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(54) Title: A POLYPEPTIDE FROM LUNG EXTRACT WHICH BINDS AMYLOID- $\beta$  PEPTIDE

(57) Abstract

The present invention provides for a method for inhibiting interaction of an amyloid- $\beta$  peptide with a receptor for advanced glycation end product on the surface of a cell which comprises contacting the cell with an agent capable of inhibiting interaction of the amyloid- $\beta$  peptide with the receptor for advanced glycation end product, the agent being present in an amount effective to inhibit interaction of the amyloid- $\beta$  peptide with the receptor for advanced glycation end product on the surface of the cell. Another embodiment of this invention is a method for evaluating the ability of an agent to inhibit binding of an amyloid- $\beta$  peptide with a receptor for advanced glycation end product on the surface of a cell which includes: a) contacting the cell with the agent and amyloid- $\beta$  peptide; b) determining the amount of amyloid- $\beta$  peptide bound to the cell and c) comparing the amount of bound amyloid- $\beta$  peptide determined in step b) with the amount determined in the absence of the agent, thus evaluating the ability of the agent to inhibit the binding of amyloid- $\beta$  peptide to the receptor for advanced glycation end product on the surface of the cell.

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A POLYPEPTIDE  
FROM LUNG EXTRACT WHICH BINDS AMYLOID- $\beta$  PEPTIDE

5 This application claims the priority of U.S. Serial No. 08/592,070, filed January 26, 1996, the contents of which are hereby incorporated by reference into the present application.

10 The invention disclosed herein was made with Government support under USPHS Grants No. AG00690, AG00603, HL21006 from the Department of Health and Human Services. Accordingly, the U.S. Government has certain rights in this invention.

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Background of the Invention

Throughout this application, various publications are referenced by author and date. Full citations for these  
20 publications may be found listed alphabetically at the end of the specification immediately preceding Sequence Listing and the claims. The disclosures of these publications in their entireties are hereby incorporated by reference into this application in order to more fully describe the state  
25 of the art as known to those skilled therein as of the date of the invention described and claimed herein.

The pathologic hallmarks of Alzheimer's disease (AD) are intracellular and extracellular accumulations of proteins,  
30 progression of which is closely correlated with eventual neuronal dysfunction and clinical dementia (for reviews see Goedert, 1993; Haass et al., 1994; Kosik, 1994; Trojanowski et al., 1994; Wischik, 1989). Amyloid- $\beta$  peptide (A $\beta$ ), which is the principal component of extracellular deposits in AD,  
35 both in senile/diffuse plaques and in cerebral vasculature, actively influences cellular functions as indicated by

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several lines of evidence: A $\beta$  has been shown to promote neurite outgrowth, generate reactive oxygen intermediates (ROIs), induce cellular oxidant stress, lead to neuronal cytotoxicity, and promote microglial activation (Behl et al., 1994; Davis et al., 1992; Hensley, et al., 1994; Koh, et al., 1990; Koo et al., 1993; Loo et al., 1993; Meda et al., 1995; Pike et al., 1993; Yankner et al., 1990). For A $\beta$  to induce these multiple cellular effects, cell surfaces may contain a binding protein(s) which engages A $\beta$ . In this context, several cell-associated proteins, as well as sulfated proteoglycans, can interact with A $\beta$ . These include: substance P receptor, the serpin-enzyme complex (SEC) receptor, apolipoprotein E, apolipoprotein J (clusterin), transthyretin, alpha-1 anti-chymotrypsin,  $\beta$ -amyloid precursor protein, and sulphonates/heparin sulfates (Abraham et al., 1988; Fraser et al., 1992; Fraser et al., 1993; Ghiso et al., 1993; Joslin et al., 1991; Kimura et al., 1993; Kisilevsky et al., 1995; Strittmatter et al., 1993a; Strittmatter et al., 1993b; Schwarzman et al., 1994; Snow et al., 1994; Yankner et al., 1990). Of these, the substance P receptor and SEC receptor might function as neuronal cell surface receptors for A $\beta$ , though direct evidence for this is lacking (Fraser et al., 1993; Joslin et al., 1991; Kimura et al., 1993; Yankner et al., 1990). In fact, the role of substance P receptors is controversial, and it is not known whether A $\beta$  alone interacts with the receptor, or if costimulators are also required (Calligaro et al., 1993; Kimura et al., 1993; Mitsuhashi et al., 1991) and the SEC receptor has yet to be fully characterized.

Amyloid- $\beta$  peptide (A $\beta$ ) is central to the pathology of Alzheimer's disease (AD), primarily because of its neurotoxic effects which involve induction of cellular oxidant stress.

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Summary of the Invention

The present invention provides for a method for inhibiting interaction of an amyloid- $\beta$  peptide with a receptor for advanced glycation end product on the surface of a cell

5 which comprises contacting the cell with an agent capable of inhibiting interaction of the amyloid- $\beta$  peptide with the receptor for advanced glycation end product, the agent being present in an amount effective to inhibit interaction of the amyloid- $\beta$  peptide with the receptor for advanced glycation

10 end product on the surface of the cell. Another embodiment of this invention is a method for evaluating the ability of an agent to inhibit binding of an amyloid- $\beta$  peptide with a receptor for advanced glycation end product on the surface of a cell which includes: a) contacting the cell with the

15 agent and amyloid- $\beta$  peptide; b) determining the amount of amyloid- $\beta$  peptide bound to the cell and c) comparing the amount of bound amyloid- $\beta$  peptide determined in step b) with the amount determined in the absence of the agent, thus evaluating the ability of the agent to inhibit the binding

20 of amyloid- $\beta$  peptide to the receptor for advanced glycation end product on the surface of the cell.

Brief Description of the Figures

Figures 1A, 1B, 1C, 1D, 1E and 1F. Colocalization of heme oxygenase type I (HO-1; A,D), p50 antigen (B, E) and RAGE (C,F) in proximity to deposits of A $\beta$  in AD brain. Figures 1A, 1B, and 1C demonstrate increased expression of HO-1, p50 and RAGE antigens, respectively, in temporal lobe. The red color shows the antigen under study (HO-1, p50 or RAGE) and the black color depicts localization of A $\beta$ . Arrows in Figure 1B depict nuclear localization of p50. Figures 1D-1F display the same antigens in cerebrovasculature from AD-derived brain. Marker bar: 50  $\mu$ m (1A,1C,1D,1F); 30  $\mu$ m (B); 125  $\mu$ m (E). Figure 1G shows ELISA for RAGE antigen in homogenates of AD brain versus age-matched apparently normal control.

Figures 2A, 2B, 2C-1, 2C-2, 2D-1, 2D-2, 2E and 2F. A $\beta$ -induction of cellular oxidant stress and binding involves association with a cell surface, trypsin-sensitive polypeptide on endothelium (A,C,E) and cortical neurons (B,D,F). A,C,E. Endothelial cells were incubated with the indicated concentration of synthetic A $\beta$  (1-40) or  $^{125}$ I-A $\beta$ , and induction of cellular oxidant stress was assessed by the TBARS assay (A) or radioligand binding studies were performed (C-1,E). Where indicated, cultures were pre-treated with probucol or N-acetylcysteine (NAC), or briefly exposed to trypsin (Figure 2C-2: +, treated with trypsin; -, controls not treated with trypsin). In Figure 2E, cross-linking of  $^{125}$ I-A $\beta$  (100 nM) to the cell surface was performed with DSS. Lanes correspond to: (1)  $^{125}$ I-A $\beta$  alone + endothelium (no DSS); (2)  $^{125}$ I-A $\beta$  with excess unlabelled A $\beta$  (100-fold), DSS and endothelium; and (3)  $^{125}$ I-A $\beta$  with DSS and endothelium; and, Figures 2B, 2D, 2F show the same experiments performed with primary cultures of rat cortical neurons instead of endothelium. Note that in Figure 2F, samples are: (1) as in E, above; (2)  $^{125}$ I-A $\beta$  with DSS and

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cortical neurons; and, (3)  $^{125}\text{I}$ -A $\beta$  with excess unlabelled A $\beta$ , DSS and cortical neurons.

Figures 3A, 3B and 3C. Purification of cellular A $\beta$ -binding polypeptide(s). Tissue extract was subjected to chromatography on heparin (A) and hydroxylapatite (B) columns. OD<sub>280</sub> of the fractions (solid line), the concentration of salt in the buffer (broken line), and fractions with peak  $^{125}\text{I}$ -A $\beta$  binding activity (arrow/bar) are shown. In Figure 3C, fractions with peak  $^{125}\text{I}$ -A $\beta$  binding activity from the hydroxylapatite column were subjected to SDS-PAGE (10%; nonreduced), and stained with Coomassie blue or sliced into 2 mm pieces, eluted, and assayed for specific  $^{125}\text{I}$ -A $\beta$  binding activity.

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Figures 4A, 4B, 4C, 4D, and 4E. Binding of  $^{125}\text{I}$ -A $\beta$  (1-40) and related peptides to RAGE: dose-dependence (A-B), effect of RAGE blockade (C) and competition (D-E). A-B. Binding of  $^{125}\text{I}$ -A $\beta$  to purified RAGE immobilized in microtiter wells was studied: 4A, the indicated concentration of RAGE was incubated for adsorption to wells ( $^{125}\text{I}$ -A $\beta$ , 100 nM); and 4B, the indicated concentration of  $^{125}\text{I}$ -A $\beta$  was added to wells pre-incubated with RAGE (5  $\mu\text{g}/\text{well}$ ). Where indicated, wells with adsorbed RAGE were preincubated with trypsin as described in the text (Figure 4A). 4C, Binding of  $^{125}\text{I}$ -A $\beta$  (100 nM) to RAGE adsorbed to microtiter wells was studied in the presence of the indicated concentration of sRAGE (2-, 20- or 50-fold molar excess), sVCAM-1 (20x), anti-RAGE IgG (10 or 50  $\mu\text{g}/\text{ml}$ ) or nonimmune IgG (10  $\mu\text{g}/\text{ml}$ ). Figure 4D-E. Competitive binding studies. Plates were coated with RAGE (5  $\mu\text{g}/\text{well}$ ) as above. In Figure 4D, wells were incubated with  $^{125}\text{I}$ -A $\beta$  (100 nM) in the presence of one of the following unlabelled competitors (in each case, an 100-fold molar excess of unlabelled peptide to  $^{125}\text{I}$ -A $\beta$  was added): Arg-Gly-Asp-Ser (Seq. I.D. No. 1)(RGDS), scrambled A $\beta$  (25-35), A $\beta$  (25-35), A $\beta$  (1-20), aggregated A $\beta$  (1-40), A $\beta$

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(1-40, fresh), and 0 denotes no addition. In Figure 4E, binding studies utilized  $^{125}\text{I}$ -A $\beta$  (100 nM) and an 100-fold excess of unlabelled A $\beta$ -derived from AD brain vasculature or plaque core, or synthetic A $\beta$  (1-40). Data shown represent 5 percent maximal specific binding, and the mean $\pm$ SEM of triplicate determinations is shown. Maximal specific binding (100%) is that observed with  $^{125}\text{I}$ -A $\beta$  (1-40; 100 nM) alone minus  $^{125}\text{I}$ -A $\beta$  + 100-fold molar excess unlabelled A $\beta$  (1-40; freshly prepared). Data were analyzed by ANOVA 10 Fisher's PLSD and the P values are \* <0.01; ^ <0.02.

Figures 5A, 5B and 5C. Role of RAGE in binding of  $^{125}\text{I}$ -A $\beta$  to mouse endothelial cells and cortical neurons: effect of sRAGE and anti-RAGE IgG. Figure 5A. Effect of sRAGE on 15 binding of  $^{125}\text{I}$ -A $\beta$  to endothelium and cortical neurons. Figure 5B-C. Effect of anti-RAGE IgG, at the indicated concentration, on binding of  $^{125}\text{I}$ -A $\beta$  to endothelium (B) or cortical neurons (C). In each case, cell cultures were incubated with  $^{125}\text{I}$ -A $\beta$  (100 nM) alone or in the presence of 20 the indicated concentrations of sRAGE, anti-RAGE IgG or nonimmune IgG (NI; 20  $\mu\text{g}/\text{ml}$ ). The mean $\pm$ SEM of quintuplicate determinations is shown. P values shown are # <0.01 and \* <0.05

25 Figures 6A, 6B, 6C and 6D. Effect of RAGE blockade on A $\beta$ -induced cellular oxidant stress in endothelial cells (A,C) and PC12 cells (B,D). Figure 6A-B. Generation of TBARS. Endothelial (A) or PC12 (B) cells were incubated with A $\beta$  (1  $\mu\text{M}$ ) either alone or in the presence of the 30 indicated amounts of anti-RAGE IgG, nonimmune IgG (NI; 20  $\mu\text{g}/\text{ml}$ ) or sRAGE (100  $\mu\text{g}/\text{ml}$ ). P values shown are \* <0.01 and # <0.05. Figure 6C-6D. Activation of NF- $\kappa\text{B}$ . The same cells were incubated with A $\beta$  alone or with other additions (as above), nuclear extracts were prepared and studied by 35 EMSA. For endothelial cells (C) and PC12 cells (D): Lane 1,  $^{32}\text{P}$ -labelled NF- $\kappa\text{B}$  probe; 2, cells not exposed to A $\beta$ ; 3,



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cells exposed to A $\beta$  (500 nM); 4-5, cells exposed to A $\beta$  (500 nM; 4) in the presence of anti-RAGE IgG or nonimmune IgG (10  $\mu$ g/ml in each case; lane 5); 6, extracts of cells exposed to A $\beta$  (500 nM) in the presence of 100-fold excess unlabelled 5 NF-KB probe.

Figures 7A, 7B, 7C, 7D, 7E, 7F, 7G and 7H. Effect of RAGE blockade on A $\beta$ -induced cellular stress in PC12 cells. Cultures were exposed to the indicated concentrations of A $\beta$  10 (25-35) alone, or in the presence of either sRAGE, anti-RAGE IgG, or nonimmune (NI) IgG. Figure 7A-D. The effect of RAGE blockade on MTT reduction is shown: A, MTT reduction at different concentrations of A $\beta$  in the presence/absence of sRAGE (20-fold molar excess over A $\beta$ ); B, MTT reduction at 15 different concentrations of sRAGE (A $\beta$ , 1  $\mu$ M); and, C-D, MTT reduction at different concentrations of A $\beta$ , anti-RAGE IgG or nonimmune IgG (10  $\mu$ g/ml). P values shown are \* $<0.01$  and # $<0.05$ . In Figure 7D, the concentration of A $\beta$  is 1  $\mu$ M. Figures 7E-H show micrographs depicting PC12 cells either 20 incubated in medium alone (E) or medium containing the following: A $\beta$  (1  $\mu$ M; F); A $\beta$  (1  $\mu$ M) + sRAGE (50  $\mu$ g/ml; G); or A $\beta$  (1  $\mu$ M) + anti-RAGE IgG (20  $\mu$ g/ml; H). Addition of nonimmune IgG in place of anti-RAGE IgG had no effect on A $\beta$ -induced morphologic changes in PC12 cells. Marker bar: 25 100  $\mu$ m.

Figures 8A-8B. RAGE expression by microglial cells. A-B. Colocalization of CD68. Figure 8A shows mouse anti-human CD68 IgG (4  $\mu$ g/ml) and RAGE. Figure 8B shows rabbit 30 anti-human RAGE IgG (30  $\mu$ g/ml) in microglia approximate to a senile plaque from AD brain (adjacent sections). Immunostaining was performed using the indicated primary antibodies.

35 Figures 9A-9B. BV-2 cells bind  $^{125}$ I-A $\beta$  in a RAGE-dependent manner. Figure 9A. Dose dependence of binding. Figure 9B.

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Inhibition of  $^{125}\text{I}$ -A $\beta$  binding by blockade of RAGE using anti-RAGE F(ab')<sub>2</sub> or sRAGE, at the indicated concentrations, but not by nonimmune F(ab')<sub>2</sub>. BV-2 cells (5x10<sup>4</sup>/well) in minimal essential medium with bovine serum albumin (1%) were incubated with either  $^{125}\text{I}$ -A $\beta$  alone (1.3x10<sup>4</sup> cpm/ng; prepared by the Iodogen method) or in the presence of one of the indicated additions at 4°C for 2 hrs. Wells were washed with Hanks balanced salt solution seven times, and cell-associated radioactivity was eluted with Nonidet P-40 (1%). Specific binding (total minus nonspecific) is shown and equilibrium binding data was analyzed as described using Enzfitter (Schmitdt, et al. 1992). Synthetic peptide was from Quality Controlled Biochemicals and AD-derived A $\beta$  was prepared (Roher, et al. 1993).

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Figures 10A, 10B and 10C. Modulation of BV-2 migration by A $\beta$ : role of RAGE. Figure 10A. Soluble A $\beta$  (1-40 and 25-35) induces chemotaxis of BV-2 cells in dose-dependent manner: effect of anti-RAGE F(ab')<sub>2</sub> or nonimmune F(ab')<sub>2</sub> on A $\beta$ (1-40 and 25-35)-induced chemotaxis. Figure 10B. Haptotoxis: effect of A $\beta$  or albumin adsorbed to the upper surface of chemotaxis chamber membranes on migration of BV-2 cells to fMLP added to the lower chamber. Figure 10C. Anti-RAGE F(ab')<sub>2</sub> blocks haptotactic response to A $\beta$ (1-40) adsorbed to chemotaxis chamber membranes. BV-2 cells were preincubated with either anti-RAGE F(ab')<sub>2</sub> or nonimmune F(ab')<sub>2</sub> for 1 hr at 4°C, cells were washed with Hanks balanced salt solution, and then added to the upper compartment of chemotaxis chambers in which the upper surface of membranes were coated with A $\beta$ (1-40). BV-2 cells (5x10<sup>3</sup>/well) were added to the upper compartment of microchemotaxis chambers for 4 hrs at 37°C, and then cells reaching the lower surface of the chemotaxis chamber membrane were visualized with Wright's stain and counted. Data are reported as cells per high-power field (HPF) based on counting nine fields/well and each experiment was performed in triplicated. Where

indicated, the upper surface of the membranes was coated with A $\beta$ (1-40) by floating in an A $\beta$  solution (50 nM) for 3 hrs at 37°C, followed by washing and drying prior to use (Schmidt, et al. 1993).

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Figures 11A, 11B and 11C. A $\beta$ -induced TNF $\alpha$  production and NF-kB activation in BV-2 cells is prevented by blocking access to RAGE. Figure 11A. A $\beta$ -induction of TNF $\alpha$  transcripts by PCR. BV-2 cells ( $10^6$ ) were incubated with 10 A $\beta$ (25-35; 500 nM) for 4 hr at 37°C, and RNA was harvested. RT-PCR was performed using primers for murine TNF $\alpha$  (Clontech) and the housekeeping gene mouse  $\beta$ -actin (Clontech) was simultaneously amplified. Ethidium bromide-stained gels are shown. The positive control (the 15 respective cDNA) and migration of standard is shown. Where indicated, BV-2 cells were pre-incubated with anti-RAGE F(ab')<sub>2</sub> or nonimmune (NI) F(ab')<sub>2</sub> (10  $\mu$ g/ml in each case) for 1 hr at 37°C. Figure 11B. A $\beta$ (25-35; 1  $\mu$ M) induction of TNF $\alpha$  antigen in BV-2 cells. Cultures were incubated for 18 20 hrs at 37°C with A $\beta$ , and cell-free supernatants were assayed for TNF $\alpha$  antigen (Biosource). Where indicated, BV-2 cells were exposed to anti-RAGE F(ab')<sub>2</sub> or nonimmune F(ab')<sub>2</sub> as above. Figure 11C. A $\beta$ (25-35)-induction of NF-kB activation in BV-2 cells. Lanes represent: (1) free probe (FP); (2) 25 BV-2 cells with medium alone; (3) BV-2 cells + A $\beta$ ; (4-5) BV-2 cells + A $\beta$  with anti-RAGE F(ab')<sub>2</sub> (2  $\mu$ g/ml [4] and 10  $\mu$ g/ml [5]); (6) BV-2 cells + A $\beta$  and nonimmune F(ab')<sub>2</sub> (10  $\mu$ g/ml); and, (7) BV-2 cells + A $\beta$  studied in the presence of an 100-fold excess of unlabelled NF-kB probe. Cultures ( $10^7$  30 cells) were exposed to A $\beta$  (1  $\mu$ M) for 4 hrs at 37°C, nuclear extracts were prepared, and gel retardation assay was performed using a double-stranded DNA oligonucleotide for the consensus NF-kB site. Where indicated, BV-2 cells were pre-incubated with anti-RAGE F(ab')<sub>2</sub> or nonimmune F(ab')<sub>2</sub> (10 35  $\mu$ g/ml) for 1 hr at 37°C and then washed twice prior to exposure to A $\beta$ .

Detailed Description of the Invention

The present invention provides for a method for inhibiting interaction of an amyloid- $\beta$  peptide with a receptor for advanced glycation end product on the surface of a cell which comprises contacting the cell with an agent capable of inhibiting interaction of the amyloid- $\beta$  peptide with the receptor for advanced glycation end product, the agent being present in an amount effective to inhibit interaction of the amyloid- $\beta$  peptide with the receptor for advanced glycation end product on the surface of the cell.

In the present invention the cell may be a neuronal cell, an endothelial cell, a glial cell, a microglial cell, a smooth muscle cell, a somatic cell, a bone marrow cell, a liver cell, an intestinal cell, a germ cell, a myocyte, a mononuclear phagocyte, an endothelial cell, a tumor cell, or a stem cell. The agent may be a peptide, a peptidomimetic, a nucleic acid or a small molecule. The peptide may be at least a portion of the sequence -Asp-Ala-Glu-Phe-Arg-His-Asp-Ser-Gly-Tyr-Glu-Val-His-His-Gln-Lys-Leu-Val-Phe-Phe-Ala-Glu-Asp-Val-Gly-Ser-Asn-Lys-Gly-Ala-Ile-Ile-Gly-Leu-Met-Val-Gly-Gly-Val-Val- (Seq. I.D. No. 2). The peptide may be at least a portion of the sequence -Gly-Ser-Asn-Lys-Gly-Ala-Ile-Ile-Gly-Leu-Met- (Seq. I.D. No. 3).

The agent may be a soluble receptor for advanced glycation end product. The agent may be a soluble extracellular portion of a receptor for advanced glycation end product, an antibody or portion thereof, wherein the antibody is capable of specifically binding to the receptor for advanced glycation endproduct. The antibody may be a monoclonal antibody or a polyclonal antibody. A portion of the antibody may be a Fab or a complementarity determining region or a variable region. The agent may be capable of specifically binding to the amyloid- $\beta$  peptide. The agent

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may bind to the amyloid- $\beta$  peptide at the site where the receptor for advanced glycation end product interacts.

One embodiment of this invention is a method for inhibiting  
5 degeneration of a neuronal cell which includes contacting the cell with an agent capable of inhibiting interaction of an amyloid- $\beta$  peptide with a receptor for advanced glycation end product on the surface of the neuronal cell.

10 Another embodiment of this invention is a method for inhibiting formation of an amyloid- $\beta$  peptide fibril on a cell which includes contacting the cell with an agent capable of inhibiting interaction of an amyloid- $\beta$  peptide with a receptor for advanced glycation end product on the  
15 surface of the cell.

Another embodiment of this invention is a method for inhibiting extracellular assembly of an amyloid- $\beta$  peptide into a fibril which includes contacting the amyloid- $\beta$   
20 peptide with an agent capable of inhibiting interaction of an amyloid- $\beta$  peptide with another amyloid- $\beta$  peptide.

Another embodiment of this invention is a method for inhibiting aggregation of amyloid- $\beta$  peptide on the surface  
25 of a cell which includes contacting the amyloid- $\beta$  peptide with an agent capable of inhibiting interaction of the amyloid- $\beta$  peptide with a receptor for advanced glycation end product.

30 Another embodiment of this invention is a method for inhibiting aggregation of amyloid- $\beta$  peptide on the surface of a cell which includes contacting the receptor for advanced glycation end product with an agent capable of inhibiting interaction of the amyloid- $\beta$  peptide with the  
35 receptor for advanced glycation end product.

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Another embodiment of this invention is a method for inhibiting infiltration of a microglial cell into senile plaques which includes contacting the microglial cell with an agent capable of inhibiting interaction of an amyloid- $\beta$  peptide with a receptor for advanced glycation end product on the surface of the microglial cell.

Another embodiment of this invention is a method for inhibiting activation of a microglial cell by an amyloid- $\beta$  peptide which includes contacting the microglial cell with an agent capable of inhibiting interaction of the amyloid- $\beta$  peptide with a receptor for advanced glycation end product on the surface of the microglial cell. The inhibition of activation may include decreased production of cytokines by the microglial cell. The interaction may be binding of the amyloid- $\beta$  peptide to the receptor for advanced glycation end product on the surface of the cell.

One embodiment of this invention is a method for treating a subject with a condition associated with interaction of an amyloid- $\beta$  peptide with a receptor for advanced glycation end product on a cell, which comprises administering to the subject an agent capable of inhibiting the interaction of the amyloid- $\beta$  peptide with the receptor for advanced glycation end product, the agent being present in an amount effective to inhibit the amyloid- $\beta$  peptide interaction with the receptor for advanced glycation end product on the cell thereby treating the subject. The condition in this embodiment may be diabetes, Alzheimer's Disease, senility, renal failure, hyperlipidemic atherosclerosis, neuronal cytotoxicity, Down's syndrome, dementia associated with head trauma, amyotrophic lateral sclerosis, multiple sclerosis or neuronal degeneration. The subject may be a mammal or a human. The administration in this embodiment may be intralesional, intraperitoneal, intramuscular or intravenous injection; infusion; liposome-mediated delivery; topical,

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nasal, oral, anal, ocular or otic delivery.

In this embodiment, the condition may be associated with degeneration of a neuronal cell in the subject, with  
5 formation of an amyloid- $\beta$  peptide fibril, with aggregation of amyloid- $\beta$  peptide, with infiltration of a microglial cell into a senile plaque, or with activation of a microglial cell by an amyloid- $\beta$  peptide, wherein the activation comprises production of cytokines by the microglial cell.

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Another embodiment of this invention is a method for evaluating the ability of an agent to inhibit binding of an amyloid- $\beta$  peptide with a receptor for advanced glycation end product on the surface of a cell which includes: a)  
15 contacting the cell with the agent and amyloid- $\beta$  peptide; b) determining the amount of amyloid- $\beta$  peptide bound to the cell and c) comparing the amount of bound amyloid- $\beta$  peptide determined in step b) with the amount determined in the absence of the agent, thus evaluating the ability of the  
20 agent to inhibit the binding of amyloid- $\beta$  peptide to the receptor for advanced glycation end product on the surface of the cell.

In this embodiment, the cell may be contacted with the agent  
25 and the amyloid- $\beta$  peptide simultaneously or the cell may be contacted with the amyloid- $\beta$  peptide and the agent. The agent may be capable of specifically binding to the amyloid- $\beta$  peptide. The agent may bind to amyloid- $\beta$  peptide at the site where the receptor for advanced glycation end product  
30 interacts. The agent may be a soluble extracellular portion of a receptor for advanced glycation end product. The agent may be bound to a solid support. The agent may be expressed on the surface of a cell.

35 Another embodiment of this invention is a method for inhibiting activation of an NF- $\kappa$ B gene in a cell which

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comprises contacting the cell with an agent which is capable of inhibiting interaction of amyloid- $\beta$  peptide with a receptor for advanced glycation endproduct on the cell, thus inhibiting activation of NF- $\kappa$ B in the cell.

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The present invention provides for a pharmaceutical composition which comprises an agent capable of inhibiting interaction of amyloid- $\beta$  peptide with a receptor for advanced glycation endproduct and a pharmaceutically acceptable carrier. The carrier may be a diluent, an aerosol, a topical carrier, an aqueous solution, a nonaqueous solution or a solid carrier.

As used herein, the term "oxidant stress" encompasses the perturbation of the ability of a cell to ameliorate the toxic effects of oxidants. Oxidants may include hydrogen peroxide or oxygen radicals that are capable of reacting with bases in the cell including DNA. A cell under "oxidant stress" may undergo biochemical, metabolic, physiological and/or chemical modifications to counter the introduction of such oxidants. Such modifications may include lipid peroxidation, NF- $\kappa$ B activation, heme oxygenase type I induction and DNA mutagenesis. Also, antioxidants such as glutathione are capable of lowering the effects of oxidants.

25

As used herein, the term "neurotoxicity" encompasses the negative metabolic, biochemical and physiological effects on a neuronal cell which may result in a debilitation of the neuronal cellular functions. Such functions may include memory, learning, perception, neuronal electrophysiology (ie. action potentials, polarizations and synapses), synapse formation, both chemical and electrical, channel functions, neurotransmitter release and detection and neuromotor functions. Neurotoxicity may include neuronal cytotoxicity.

35

As used herein, the term "neuronal degeneration" encompasses



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a decline in normal functioning of a neuronal cell. Such a decline may include a decline in memory, learning, perception, neuronal electrophysiology (ie. action potentials, polarizations and synapses), synapse formation, 5 both chemical and electrical, channel functions, neurotransmitter release and detection and neuromotor functions. In the present invention, the subject may be a mammal or a human subject. The administration may be intralesional, intraperitoneal, intramuscular or intravenous 10 injection; infusion; liposome-mediated delivery; gene bombardment; topical, nasal, oral, anal, ocular or otic delivery.

In the practice of any of the methods of the invention or 15 preparation of any of the pharmaceutical compositions an "therapeutically effective amount" is an amount which is capable of inhibiting the binding of an amyloid- $\beta$  peptide with a receptor for advanced glycation endproduct. Accordingly, the effective amount will vary with the subject 20 being treated, as well as the condition to be treated. For the purposes of this invention, the methods of administration are to include, but are not limited to, administration cutaneously, subcutaneously, intravenously, parenterally, orally, topically, or by aerosol.

25

As used herein, the term "suitable pharmaceutically acceptable carrier" encompasses any of the standard pharmaceutically accepted carriers, such as phosphate buffered saline solution, water, emulsions such as an 30 oil/water emulsion or a triglyceride emulsion, various types of wetting agents, tablets, coated tablets and capsules. An example of an acceptable triglyceride emulsion useful in intravenous and intraperitoneal administration of the compounds is the triglyceride emulsion commercially known as 35 Intralipid®.

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Typically such carriers contain excipients such as starch, milk, sugar, certain types of clay, gelatin, stearic acid, talc, vegetable fats or oils, gums, glycols, or other known excipients. Such carriers may also include flavor and color  
5 additives or other ingredients.

This invention also provides for pharmaceutical compositions including therapeutically effective amounts of protein compositions and compounds capable of inhibiting the binding  
10 of an amyloid- $\beta$  peptide with a receptor for advanced glycation endproduct in the subject of the invention together with suitable diluents, preservatives, solubilizers, emulsifiers, adjuvants and/or carriers useful in treatment of neuronal degradation due to aging, a  
15 learning disability, or a neurological disorder. Such compositions are liquids or lyophilized or otherwise dried formulations and include diluents of various buffer content (e.g., Tris-HCl., acetate, phosphate), pH and ionic strength, additives such as albumin or gelatin to prevent  
20 absorption to surfaces, detergents (e.g., Tween 20, Tween 80, Pluronic F68, bile acid salts), solubilizing agents (e.g., glycerol, polyethylene glycerol), anti-oxidants (e.g., ascorbic acid, sodium metabisulfite), preservatives (e.g., Thimerosal, benzyl alcohol, parabens), bulking  
25 substances or tonicity modifiers (e.g., lactose, mannitol), covalent attachment of polymers such as polyethylene glycol to the compound, complexation with metal ions, or incorporation of the compound into or onto particulate preparations of polymeric compounds such as polylactic acid,  
30 polglycolic acid, hydrogels, etc, or onto liposomes, micro emulsions, micelles, unilamellar or multi lamellar vesicles, erythrocyte ghosts, or spheroplasts. Such compositions will influence the physical state, solubility, stability, rate of in vivo release, and rate of in vivo clearance of the  
35 compound or composition. The choice of compositions will

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depend on the physical and chemical properties of the compound capable of alleviating the symptoms of the cognitive disorder of memory or the learning disability in the subject.

5

Controlled or sustained release compositions include formulation in lipophilic depots (e.g., fatty acids, waxes, oils). Also comprehended by the invention are particulate compositions coated with polymers (e.g., poloxamers or  
10 poloxamines) and the compound coupled to antibodies directed against tissue-specific receptors, ligands or antigens or coupled to ligands of tissue-specific receptors. Other embodiments of the compositions of the invention incorporate particulate forms protective coatings, protease inhibitors  
15 or permeation enhancers for various routes of administration, including parenteral, pulmonary, nasal and oral.

Portions of the compound of the invention may be "labeled"  
20 by association with a detectable marker substance (e.g., radiolabeled with <sup>125</sup>I or biotinylated) to provide reagents useful in detection and quantification of compound or its receptor bearing cells or its derivatives in solid tissue and fluid samples such as blood, cerebral spinal fluid or  
25 urine.

When administered, compounds are often cleared rapidly from the circulation and may therefore elicit relatively short-lived pharmacological activity. Consequently, frequent  
30 injections of relatively large doses of bioactive compounds may be required to sustain therapeutic efficacy. Compounds modified by the covalent attachment of water-soluble polymers such as polyethylene glycol, copolymers of polyethylene glycol and polypropylene glycol, carboxymethyl  
35 cellulose, dextran, polyvinyl alcohol, polyvinylpyrrolidone

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or polyproline are known to exhibit substantially longer half-lives in blood following intravenous injection than do the corresponding unmodified compounds (Abuchowski et al., 1981; Newmark et al., 1982; and Katre et al., 1987). Such 5 modifications may also increase the compound's solubility in aqueous solution, eliminate aggregation, enhance the physical and chemical stability of the compound, and greatly reduce the immunogenicity and reactivity of the compound. As a result, the desired in vivo biological activity may be 10 achieved by the administration of such polymer-compound adducts less frequently or in lower doses than with the unmodified compound.

Attachment of polyethylene glycol (PEG) to compounds is 15 particularly useful because PEG has very low toxicity in mammals (Carpenter et al., 1971). For example, a PEG adduct of adenosine deaminase was approved in the United States for use in humans for the treatment of severe combined immunodeficiency syndrome. A second advantage afforded by 20 the conjugation of PEG is that of effectively reducing the immunogenicity and antigenicity of heterologous compounds. For example, a PEG adduct of a human protein might be useful for the treatment of disease in other mammalian species without the risk of triggering a severe immune response. 25 The compound of the present invention capable of alleviating symptoms of a cognitive disorder of memory or learning may be delivered in a microencapsulation device so as to reduce or prevent an host immune response against the compound or against cells which may produce the compound. The compound 30 of the present invention may also be delivered microencapsulated in a membrane, such as a liposome.

Polymers such as PEG may be conveniently attached to one or more reactive amino acid residues in a protein such as the 35 alpha-amino group of the amino terminal amino acid, the

epsilon amino groups of lysine side chains, the sulfhydryl groups of cysteine side chains, the carboxyl groups of aspartyl and glutamyl side chains, the alpha-carboxyl group of the carboxy-terminal amino acid, tyrosine side chains, or 5 to activated derivatives of glycosyl chains attached to certain asparagine, serine or threonine residues.

Numerous activated forms of PEG suitable for direct reaction with proteins have been described. Useful PEG reagents for 10 reaction with protein amino groups include active esters of carboxylic acid or carbonate derivatives, particularly those in which the leaving groups are N-hydroxysuccinimide, p-nitrophenol, imidazole or 1-hydroxy-2-nitrobenzene-4-sulfonate. PEG derivatives containing maleimido or 15 haloacetyl groups are useful reagents for the modification of protein free sulfhydryl groups. Likewise, PEG reagents containing amino hydrazine or hydrazide groups are useful for reaction with aldehydes generated by periodate oxidation of carbohydrate groups in proteins.

20

The pathologic hallmarks of Alzheimer's disease (AD) are intracellular and extracellular deposition of filamentous proteins which closely correlates with eventual neuronal dysfunction and clinical dementia (for reviews see Goedert, 25 1993; Haass et al., 1994; Kosik, 1994; Trojanowski et al., 1994; Wischik, 1989). Amyloid- $\beta$  peptide (A $\beta$ ) is the principal component of extracellular deposits in AD, both in senile/diffuse plaques and in cerebral vasculature. A $\beta$  has been shown to promote neurite outgrowth, generate reactive 30 oxygen intermediates (ROIs), induce cellular oxidant stress, lead to neuronal cytotoxicity, and promote microglial activation (Behl et al., 1994; Davis et al., 1992; Hensley, et al., 1994; Koh, et al., 1990; Koo et al., 1993; Loo et al., 1993; Meda et al., 1995; Pike et al., 1993; Yankner et 35 al., 1990). For A $\beta$  to induce these multiple cellular effects, it is likely that plasma membranes present a

-20-

binding protein(s) which engages A $\beta$ . In this context, several cell-associated proteins, as well as sulfated proteoglycans, can interact with A $\beta$ . These include: substance P receptor, the serpin-enzyme complex (SEC) 5 receptor, apolipoprotein E, apolipoprotein J (clusterin), transthyretin, alpha-1 anti-chymotrypsin,  $\beta$ -amyloid precursor protein, and sulphonates/heparan sulfates (Abraham et al., 1988; Fraser et al., 1992; Fraser et al., 1993; Ghiso et al., 1993; Joslin et al., 1991; Kimura et al., 10 1993; Kisilevsky et al., 1995; Strittmatter et al., 1993a; Strittmatter et al., 1993b; Schwarzman et al., 1994; Snow et al., 1994; Yankner et al., 1990). Of these, the substance P receptor and SEC receptor might function as neuronal cell surface receptors for A $\beta$ , though direct evidence for this is 15 lacking (Fraser et al., 1993; Joslin et al., 1991; Kimura et al., 1993; Yankner et al., 1990). In fact, the role of substance P receptors is controversial, and it is not known whether A $\beta$  alone interacts with the receptor, or if costimulators are required (Calligaro et al., 1993; Kimura 20 et al., 1993; Mitsuhashi et al., 1991) and the SEC receptor has yet to be fully characterized.

This invention is illustrated in the Experimental Details section which follows. These sections are set forth to aid 25 in an understanding of the invention but are not intended to, and should not be construed to, limit in any way the invention as set forth in the claims which follow thereafter.

EXPERIMENTAL DETAILSExample 1: A Receptor Mediating Amyloid- $\beta$  Peptide-induced Oxidant Stress and Neurotoxicity

5

Amyloid- $\beta$  peptide (A $\beta$ ) is central to the pathology of Alzheimer's disease (AD), primarily because of its neurotoxic effects which involve induction of cellular oxidant stress. A cell-associated ~50 kDa polypeptide which  
10 binds A $\beta$  peptide (1-40) was purified to homogeneity and was shown to be identical to RAGE, an immunoglobulin superfamily member which also serves as a receptor for both amphotericin, a group I DNA binding protein involved in neuritic outgrowth, and advanced glycation endproducts (AGEs).  
15 Recombinant RAGE bound  $^{125}$ I-A $\beta$  (1-40) in a dose-dependent manner; binding was blocked by excess A $\beta$  purified from AD brain and by unlabelled synthetic A $\beta$  (1-40 and 25-35) but not by A $\beta$  (1-20). Binding of  $^{125}$ I-A $\beta$  to cultured cortical neurons was prevented by anti-RAGE IgG or excess soluble  
20 RAGE. In addition, blocking access to RAGE prevented A $\beta$ -induced cellular oxidant stress and cytotoxicity. Increased expression of RAGE in neurons proximate to senile plaques in AD brain, which also display evidence of oxidant stress and cytotoxicity, further suggests the relevance of  
25 RAGE-A $\beta$  interaction to cellular dysfunction and ultimate neurodegeneration, and is consistent with the concept that this interaction might be critical in the pathogenesis of AD.

## 30 Introduction

The possibility exists that another/other cellular binding site(s) might be present which could tether A $\beta$  to the cell surface. The importance of identifying such receptors is  
35 evident from the probability that A $\beta$  closely associated with the cell surface might trigger reactions generating potent

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oxidizing stimuli capable of inducing cytotoxicity. If this hypothesis is correct, blocking access of A $\beta$  to the cell surface binding site(s) might considerably retard progression of cellular dysfunction in AD.

5

This study reports the isolation and characterization of a ~50 kDa polypeptide which binds synthetic A $\beta$  peptide (1-40) and is identical to RAGE (the Receptor for Advanced Glycation Endproducts). RAGE, previously identified as a  
10 central cellular receptor for Advanced Glycation Endproducts (AGEs; Schmidt et al. 1992; Neeper et al., 1992) also serves as a neuronal receptor for amphoterin, a molecule involved in neurite outgrowth (Rauvala et al., 1987). It is shown herein that RAGE mediates the interaction of A $\beta$  with  
15 endothelial cells (ECs) and neuronal-like cells, as demonstrated by radioligand binding experiments, as well as by its ability to mediate cellular oxidant stress and neuronal cytotoxicity. Enhanced expression of RAGE in AD, both in affected neurons and the vasculature, is consistent  
20 with the possibility that A $\beta$ -RAGE interaction may be relevant to the cytotoxicity central to this dementia.

## Results

### Relationship between oxidant stress markers and A $\beta$ in AD

25 brain. Previous studies have demonstrated an association between neuronal injury in AD and oxidant stress (Coyle et al., 1993; Hensley, 1994; Volicer et al., 1990) by expression of heme oxygenase type 1 (HO-1), nuclear localization of the p50 subunit of NF-kB, and expression of  
30 malondialdehyde-lysine epitopes (Smith et al., 1994; Yan et al., 1994; Yan et al., 1995). Although extracellular A $\beta$  can induce oxidant stress in neurons *in vitro* (Behl et al., 1994; Hensley et al., 1994), this would probably be attenuated *in vivo* by the presence of abundant antioxidants.  
35 Nevertheless, neurons proximate to senile plaques displayed HO-1, and elevated levels of the p50 subunit of the NF-kB



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family (Fig. 1A-B, respectively). Increased expression of p50 was especially prominent in a nuclear distribution (see arrows in Fig 1B), suggestive of its activation. Deposition of A $\beta$  also occurs in the cerebral vasculature (Glenner, 5 1979; Kawai et al., 1992; Luthert et al., 1991; Yamaguchi et al., 1992); oxidant stress (increased HO-1 and p50) was also evident in those vessels with accumulated A $\beta$  (Fig. 1D-E). Expression of HO-1 and p50 was enhanced in both endothelial cells and smooth muscle cells. In contrast, cerebral 10 vasculature from age-matched controls showed minimal staining for HO-1 and p50. These observations suggested a spatial association between A $\beta$  deposition and the expression of markers of enhanced cellular oxidant stress in AD brain, leading to the hypothesis that binding of A $\beta$  to specific 15 cellular structures might promote such perturbation of cellular properties, in spite of the antioxidant milieu prevalent in vivo.

Characterization of the interaction of A $\beta$  with ECs and  
20 neuronal-like cells. Signs of oxidant stress in AD lead to the interaction of A $\beta$  with vascular cells and with neurons, and the consequences for perturbation of cellular functions. Incubation of synthetic A $\beta$  (1-40) with ECs from murine cerebral vasculature or rat cortical neurons cells resulted 25 in a dose-dependent increase in thiobarbituric acid-reactive substances (TBARS), which was blocked by pre-treatment of cultures with probucol or N-acetylcysteine (NAC) suggestive of an oxidant-sensitive mechanism (Fig. 2A-B). These results are consistent with what has been reported 30 previously with neurons exposed to A $\beta$  (Behl et al., 1994; Harris et al., 1995; Mattson et al., 1995). To test the possibility that A $\beta$ -induced cellular oxidant stress involved interaction with a cell surface polypeptide, endothelial cells or cortical neurons were briefly treated with trypsin, 35 the enzyme was neutralized and cells then exposed to A $\beta$ . Trypsin treatment virtually completely blocked appearance of

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TBARS (Fig. 2A-B), though it had no effect on detection of TBARS when added after cells had been pre-incubated with A $\beta$ . Similar experiments examining induction of HO-1 mRNA and nuclear translocation of NF-kB showed cellular activation by 5 A $\beta$ , which was prevented by pretreatment of cultures with trypsin. Studies with PC12 cells provided similar results. These data strongly supported a role for a trypsin-sensitive cell surface polypeptide in A $\beta$ -induction of cellular oxidant stress.

10

Reasoning that such a cell surface structure was likely to function, at least in part, as a binding site to tether A $\beta$  to the cell, radioligand binding studies were performed. When synthetic A $\beta$  peptide (residues 1-40) was radiolabelled, 15 specific and dose-dependent binding of  $^{125}$ I-A $\beta$  to cultured ECs was observed (Fig. 2C). Half-maximal binding occurred at an  $^{125}$ I-A $\beta$  concentration of  $40.0 \pm 9.79$  nM and, at saturation, there were  $\approx 1.7 \times 10^6$  molecules bound per cell. Exposure of cultures to trypsin blocked binding of  $^{125}$ I-A $\beta$  20 (Fig. 2C, inset). Concentrations of  $^{125}$ I-A $\beta$  which increased occupancy of cell surface binding sites were comparable to those inducing endothelial generation of TBARS (Fig. 2A). Further supporting a central role for a cell surface binding site is clear from the strong inhibitory effect of trypsin 25 on both  $^{125}$ I-A $\beta$  binding and A $\beta$ -mediated oxidant stress. Similarly, radioligand binding studies on cultured rat cortical neurons displayed dose-dependent  $^{125}$ I-A $\beta$  binding,  $K_d$   $55.2 \pm 14.6$  nM, which was blocked by pre-treatment of cells with trypsin (Fig. 2D).

30

To further identify the nature of cell surface polypeptide(s) with which  $^{125}$ I-A $\beta$  was interacting, crosslinking studies were performed. ECs with surface-bound  $^{125}$ I-A $\beta$  were exposed to disuccinimidyl suberate (DSS; 0.2 mM) 35 and extracts were prepared for SDS-PAGE and autoradiography (Fig. 2E). A single major band,  $M_r \approx 50-55$  kDa was observed

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(Fig. 2E, lane 3), whose intensity was greatly attenuated upon addition of an 100-fold molar excess of unlabelled A $\beta$  (Fig. 2E, lane 2). Ruling out the possibility that this band was due to self-aggregation of the tracer, when  $^{125}$ I-A $\beta$  was incubated with DSS under the same conditions in the absence of ECs, no band was observed. Similar cross-linking studies on cortical neurons also showed that  $^{125}$ I-A $\beta$  became associated with a polypeptide of  $M_r$   $\approx$ 50-55 kDa (Fig. 2F, lane 2).

10

Before proceeding further with characterization of the  $\approx$ 55 kDa polypeptide, it was important to determine whether cell-associated  $^{125}$ I-A $\beta$  was interacting with previously recognized A $\beta$ -binding proteins, such as apolipoproteins E and J, heparin-like and heparan sulfate proteoglycans, substance P receptors, and transthyretin. Pre-treatment of ECs with heparin (10  $\mu$ g/ml), which has been shown to release cell-associated apo E (Ji et al., 1994) or preincubation with heparanase (under conditions which blocked 80% of  $^{125}$ I-basic fibroblast growth factor binding to ECs, due to cell surface and matrix heparan sulfate proteoglycans; Moscatelli, 1992) did not affect  $^{125}$ I-A $\beta$  binding to endothelium. Pilot studies in which substance P (added as an unlabelled competitor) or antibody to transthyretin was present during the incubation of  $^{125}$ I-A $\beta$  with ECs had no effect on binding. Apo J, with  $M_r$   $\approx$ 80 kDa (Ghiso et al., 1993), was unlikely to be responsible for the  $\approx$ 55 kDa band observed on SDS-PAGE following crosslinking of  $^{125}$ I-A $\beta$  to the cell surface. These studies suggested that the cell-associated A $\beta$  binding polypeptide under study here was distinct from previously described species.

Isolation and characterization of A $\beta$  cell-associated binding proteins. In order to purify cellular A $\beta$  binding proteins, a binding assay was developed employing extracts of cultured cells or tissues immobilized on microtiter wells and  $^{125}$ I-A $\beta$ .

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The first studies used ECs, as their binding of  $^{125}\text{I}$ -A $\beta$  was similar to that of neurons, and because they are easier to culture and obtain in larger numbers. ECs were extracted with octyl- $\beta$ -glucoside in the presence of protease inhibitors, diluted in carbonate/bicarbonate buffer, and the mixture was adsorbed to microtiter wells. Specific binding of  $^{125}\text{I}$ -A $\beta$  was similar to that observed on cultured ECs: it was dose-dependent ( $K_d$  32.9 $\pm$ 10.2 nM) and completely prevented by pre-treatment of the cell extract with trypsin. To further scale up starting material for purification of cell-associated A $\beta$  binding proteins, acetone-extract of bovine lung was tested using a similar assay following adsorption to microtiter wells and incubation with  $^{125}\text{I}$ -A $\beta$ . Again, similar specific, trypsin-sensitive, and dose-dependent binding was observed. Although extract of brain, especially from patients with AD, would have been a more appropriate starting material for purification of A $\beta$  binding polypeptides, studies showed that brain extract, though in many respects comparable to lung extract, was not a convenient starting material. Results of binding assays with brain extract were not reproducible, probably due to the high content of lipid, and human brain, especially patient-derived tissue, was not available in sufficient quantity.

25

The preparation of A $\beta$  binding protein(s) from lung was performed by subjecting acetone extract of the tissue to sequential chromatography on heparin and hydroxylapatite columns. Following application of tissue extract, the heparin column was washed with equilibration buffer and eluted with ascending concentrations of NaCl (Fig. 3A).  $^{125}\text{I}$ -A $\beta$  binding activity was observed in the eluate, as indicated (maximal activity, 0.5 M NaCl), and fractions were pooled, dialyzed and applied to hydroxylapatite. The column was eluted with increasing concentrations of phosphate, and fractions corresponding to 0.25 M displayed the highest

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binding activity for  $^{125}\text{I}$ -A $\beta$  (Fig. 3B). This material was concentrated and applied to preparative nonreduced SDS-PAGE (10%), and two major bands were observed corresponding to  $M_r$ 's of 30-35 and 50-60 kDa (Fig. 3C). Another lane of the same gel loaded with the same sample was sliced into 2 mm pieces, and each piece subjected to gel elution; the eluate was studied in the  $^{125}\text{I}$ -A $\beta$  binding assay. Each of the two major protein bands demonstrated the capacity to specifically bind  $^{125}\text{I}$ -A $\beta$  (Fig. 3C). In contrast, gel elution of lanes in which molecular weight standards were run in place of test samples revealed no binding of  $^{125}\text{I}$ -A $\beta$ .

Using the same gel system as above, bands were cut-out and subjected to N-terminal sequence analysis. The ~50 kDa band was sequenced first as it was most abundant. The sequence revealed virtual identity with bovine RAGE (Table 1).

Table 1 - Amino acid sequences of the ~50kDa GEL BAND AND 30-35 kDa gel band: Comparison to RAGE

	RAGE NH <sub>2</sub> -terminal	DQNITARIGKPLVLNCKGAPKKPPQOLEWK <sup>a</sup>
20	NH <sub>2</sub> -terminal ~50kDa gel	DQXITARIGKPLVLNXXGAPKKPPQOLEW(K) <sup>b</sup>
	NH <sub>2</sub> -terminal 30-35 kDa gel band	DQXITARIGKPLVLNXXGAP <sup>c</sup>

The following abbreviations were used: X, no residue identifiable at that cycle; parenthesis, tentative assignment. (Neeper et al. 1992). <sup>a</sup>Seq. I.D. No. 8; <sup>b</sup> Seq. I.D. No. 9; <sup>c</sup>Seq. I. D. No. 10)

Based on protein structure deduced from the bovine RAGE cDNA and immunoblotting results (Neeper et al., 1992; Brett et al., 1993), the ~50 kDa band would most likely correspond to full-length RAGE. The 30-35 kDa band also demonstrated the same N-terminal sequence as RAGE, and most likely represented the extracellular domain of RAGE which has been observed previously to undergo proteolysis during purification (Schmidt et al., 1992). Consistent with these data, both 30-35 and ~50 kDa polypeptides were reactive with

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anti-RAGE IgG prepared against recombinant human RAGE. A minor, more slowly migrating peak of A $\beta$  binding activity, corresponding to  $M_r$   $\approx$ 66 kDa (Fig. 3C), gave two N-terminal sequences, that for RAGE and albumin.

5

Binding of  $^{125}$ I-A $\beta$  to RAGE. The interaction of RAGE with A $\beta$  was further characterized by radioligand binding studies, using purified recombinant human RAGE (a form consisting of the extracellular domain termed soluble or sRAGE) expressed  
10 in a baculovirus system (Hori et al., 1995). Following adsorption of RAGE to microtiter wells, specific binding of  $^{125}$ I-A $\beta$  (binding observed with  $^{125}$ I-A $\beta$  alone minus that observed with  $^{125}$ I-A $\beta$  and excess unlabelled A $\beta$ ) was dependent on the concentration of RAGE incubated with the wells (Fig.  
15 4A). No specific binding was observed when RAGE was replaced by albumin. Exposure of RAGE-coated wells to trypsin (Fig. 4A) completely blocked subsequent binding of  $^{125}$ I-A $\beta$ , as expected from our previous observation that RAGE is inactivated by trypsin (Schmidt et al., 1992). When the  
20 concentration of RAGE adsorbed to wells was held constant, and varying amounts of  $^{125}$ I-A $\beta$  were added, binding was dose-dependent with half-maximal occupancy of binding sites at  $56.8 \pm 13.9$  nM (Fig. 4B). This was similar to the range of A $\beta$  concentrations resulting in binding to and oxidant stress  
25 in endothelial cells, PC12 cells and cortical neurons. Addition of either anti-RAGE IgG or soluble RAGE simultaneous with  $^{125}$ I-A $\beta$  resulted in dose-dependent inhibition of binding (Fig. 4C), whereas nonimmune (NI) rabbit IgG or another immunoglobulin superfamily molecule,  
30 vascular cell adhesion molecule-1 (VCAM-1; Osborn, 1989) was without effect. These data indicate that RAGE binds synthetic  $^{125}$ I-A $\beta$  peptide (1-40).

Competition studies were performed to assess the region of  
35 A $\beta$  (1-40) interacting with RAGE and to evaluate the effect of A $\beta$  purified from AD brain (Fig. 4D-E). In the presence

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of freshly-prepared unlabelled A $\beta$  (1-40), binding of  $^{125}$ I-A $\beta$  to RAGE was blocked (Fig. 4D). Competition was also observed if A $\beta$  (1-40) was allowed to incubate for 3 days at 37°C, conditions which promote aggregation of the peptide (Hensley et al., 1994; Lorenzo et al., 1994). A truncated form of A $\beta$  (1-40) consisting of residues 25-35 also inhibited binding of  $^{125}$ I-A $\beta$  to RAGE. In accord with the specificity of A $\beta$ -RAGE interaction, addition of excess unlabelled A $\beta$  (1-20), scrambled A $\beta$  (25-35), or an irrelevant peptide such as Arg-Gly-Asp-Ser (Seq. I.D. No. 1) had no effect on  $^{125}$ I-A $\beta$  binding to RAGE (Fig. 4D). Furthermore, human A $\beta$  (1-40/1-42), chromatographically-purified from neuritic plaques or vascular amyloid from brains of patients with AD (Roher et al., 1993a; Roher et al., 1993b), inhibited the binding of  $^{125}$ I-A $\beta$  (Fig. 4E).

As a first step in understanding whether RAGE would mediate the binding of A $\beta$  to cells, radioligand binding studies were performed with cultured mouse brain endothelial cells (Fig. 5A, 5B) and rat cortical neurons (Fig. 5A, 5C). In each case, binding of  $^{125}$ I-A $\beta$  was blocked by addition of excess soluble RAGE or anti-RAGE IgG in a dose-dependent manner. These data indicated that RAGE functioned as a binding site for  $^{125}$ I-A $\beta$  on cellular surfaces.

25

RAGE and A $\beta$ -induced cellular stress. A series of experiments suggested that A $\beta$  interaction with RAGE mediates cellular perturbations resulting in oxidant stress and cytotoxicity. Endothelial cells exposed to A $\beta$  generated TBARS (Fig. 2A and 6A); this was prevented by blocking access to RAGE using either anti-RAGE IgG or excess soluble receptor (Fig. 6A). Another index of oxidant stress triggered by A $\beta$ , activation of NF-kB in ECs, was also suppressed by blocking RAGE (Fig. 6C, compare lanes 3 and 4). Similar experiments on PC12 cells with A $\beta$  showed generation of TBARS (Fig. 6B) and activation of NF-kB (Fig.

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6D, compare lanes 3 and 4), also prevented by blocking interaction of A $\beta$  with the receptor.

Because A $\beta$  is well-known for its toxicity to a range of  
5 cultured neurons and neuronal-related cells (Behl et al.,  
1994; Harris et al., 1995; Hensley et al., 1994; Koh et al.,  
1990; Loo et al., 1993; Lorenzo et al., 1994; Pike et al.,  
1993; Yankner et al., 1990), it was important to determine  
if A $\beta$ -RAGE interaction mediated such effects of the peptide.  
10 Incubation of PC12 cells with A $\beta$  (25-35) resulted in  
dose-dependent cytotoxic/stress-associated changes,  
including perturbation of cellular reduction of  
3-(4,5-dimethylthiazol-2-yl)-2,5, diphenyl tetrazolium  
bromide (MTT; Fig. 7A). This biochemical index of cellular  
15 stress was accompanied by morphologic changes, including  
retraction of cellular processes (Fig. 7, compare panels  
E-F). Addition of sRAGE (Fig. 7A-B, G) or anti-RAGE IgG  
(Fig. 7C-D, H) prevented A $\beta$ -induced cellular stress, based  
on each of these criteria. Similar results were observed  
20 when PC12 cells were incubated with A $\beta$ (1-40).

RAGE expression in AD. The above data suggested that RAGE,  
if present and/or up-regulated in cells likely to be  
critical in the pathogenesis of AD, might participate in  
25 mediating toxic effects when associated with A $\beta$  and related  
peptides. ELISA of homogenates of AD brain demonstrated  
~2.5-fold increase in patients compared with age-matched  
controls (Fig. 1G). Immunocytochemical studies showed  
increased expression of RAGE (Fig. 1C) in neurons displaying  
30 evidence of oxidant stress (Fig. 1A-B) proximate to deposits  
of A $\beta$ . In the vasculature, RAGE expression was also  
enhanced in the vessel wall (Fig. 1F), in cellular elements  
showing increased HO-1 and p50 (Fig. 1D-E) in the vicinity  
of A $\beta$  deposition. Closer examination of vessel walls showed  
35 RAGE to be enhanced in both endothelium and smooth muscle  
cells. In contrast, RAGE expression was minimal in



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age-matched cerebral vasculature from apparently normal controls. Thus, RAGE expression appears to be significantly upregulated in neuronal elements around or participating in the neuritic plaques as well as in the vascular cells of the 5 affected AD brain.

### Discussion

RAGE is a member of the immunoglobulin superfamily of cell 10 surface molecules originally identified by its capacity to bind advanced glycation endproducts (AGEs; Schmidt et al., 1992; Neeper et al., 1993). These irreversibly nonenzymatically glycated adducts, which form on free amino groups, accumulate in tissues during normal aging, and their 15 deposition is accelerated in diabetes, renal failure, and settings in which macromolecular turnover is delayed (Baynes, 1991; Ruderman et al., 1992). As AGEs have been localized to the vasculature, especially in diabetes and experimental hyperlipidemic atherosclerosis (Nakamura et 20 al., 1993; Palinski et al., 1995), the first characterization of RAGE in these studies emphasized its role as a cell surface receptor for AGEs on endothelial cells and mononuclear phagocytes. AGE-RAGE interaction mediates perturbation of central properties of each of these 25 cell types for vascular homeostasis: vascular permeability is increased, endothelial expression of VCAM-1 is induced, monocyte migration is stimulated and production of proinflammatory cytokines, such as tumor necrosis factor-alpha occurs (Schmidt et al., 1993; Schmidt et al., 30 1995; Wautier et al., 1995;).

In addition to the vasculature, expression of RAGE is especially prominent in the central nervous system (Brett et al., 1993; Hori et al., 1995). During the embryonic and 35 early postnatal period in rat brain, RAGE is highly expressed by cortical neurons in hippocampus (P5) and

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cerebellum (P17). These observations strongly suggested that AGEs were almost certainly not the primary ligands of RAGE, and led to studies to seek another ligand which could engage RAGE and affect cellular function, distinct from those consequent on AGE-RAGE interaction. This ligand proved to be amphoterin, a high mobility group I DNA binding protein which is highly expressed in developing neurons and has been shown to mediate neurite outgrowth when present extracellularly (Rauvala et al., 1987). Amphoterin binds to RAGE specifically and with high affinity ( $K_d \sim 9$  nM; Hori et al., 1995); radioligand binding studies with  $^{125}\text{I}$ -amphoterin showed RAGE to be the receptor mediating its binding to cortical neurons, as well as subsequent induction of neurite outgrowth. Furthermore, neurons containing RAGE in developing rat cerebral cortex also expressed, or were contiguous to other cells which expressed amphoterin, suggesting that amphoterin-RAGE interaction was occurring under physiologic conditions (Hori et al., 1995). Although detailed neuroanatomical studies of RAGE expression have not yet been done, the receptor clearly displays more limited expression in the adult central nervous system compared with the early perinatal period. In adult animals, RAGE is found in a population of cortical neurons yet to be characterized and in spinal motor neurons (Brett et al., 1993). In Alzheimer's disease, expression of RAGE within cortical neurons increases and is more widespread, especially in those neurons proximate to deposits of A $\beta$  and those cells bearing neurofibrillary tangles. This suggested that there was yet another ligand for RAGE under pathologic conditions, such as in AD brain.

As findings concerning RAGE expression in AD were emerging, independent investigation into how A $\beta$  induced cellular oxidant stress was ongoing. A $\beta$  itself has been shown to generate ROIs (Hensley et al., 1994) and A $\beta$  interaction with PC12 cells additionally triggers intracellular formation of

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oxidants (Behl et al., 1994), such as hydrogen peroxide, resulting in perturbation of a range of cellular properties. Expression of markers associated with cellular oxidant stress in AD brain has been demonstrated, including HO-1, 5 activation of NF-kB and the presence of malondialdehyde-lysine epitopes (Smith et al., 1994; Yan et al., 1994; Yan et al., 1995). As antioxidant mechanisms abound in the extracellular space, it seemed that A $\beta$  engagement of a cell surface polypeptide would tether A $\beta$  to 10 the membrane where it could exert its oxidant effects in proximity to cellular structures. Consistent with this concept, binding of A $\beta$  to cortical neurons paralleled the induction of cellular oxidant stress, and both were blocked by pre-treatment of cultures with trypsin. Two lines of 15 investigation, one to understand the role of RAGE in AD brain and the other to identify cellular binding site(s) for A $\beta$  that mediate induction of cellular oxidant stress, converged when the N-terminal sequence of the cellular A $\beta$  binding protein proved to be identical to RAGE. Experiments 20 with recombinant RAGE and blocking antibody to the receptor further confirmed that RAGE specifically bound A $\beta$  and mediated, in large part, A $\beta$  binding to cortical neurons, as well as A $\beta$  induction of oxidant stress and neurotoxicity.

25 The interaction of A $\beta$  with RAGE was dose-dependent and specific, and appeared to involve the region comprising residues 25-35 of the peptide. As this portion of A $\beta$  has been shown to participate in A $\beta$ -mediated cytotoxicity and self-aggregation (Loo et al., 1993; Hensley et al., 1994; 30 Mattson et al., 1995; Shearman et al., 1994), it is possible that RAGE might act as a magnet to localize forming amyloid fibrils to the cell surface. Such a role for RAGE would emphasize its capacity for promoting the cytotoxicity of A $\beta$ , but may reflect an initially protective mechanism, intended 35 to mediate clearance of A $\beta$  monomers or small aggregates, gone awry in a sea of large A $\beta$  aggregates in AD brain.

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Addition of excess extracellular domain of RAGE (sRAGE) completely blocked  $^{125}\text{I}$ -A $\beta$  binding to both ECs and cortical neurons. When present in sufficient molar excess to A $\beta$ , sRAGE also completely prevented A $\beta$ -induced neuronal toxicity; at higher levels of A $\beta$ , e.g. 10  $\mu\text{M}$ , sufficient concentrations of soluble receptor could not be achieved for complete neuroprotection. Anti-RAGE IgG prevented  $^{125}\text{I}$ -A $\beta$  binding to cortical neurons by only  $\sim 70\%$ , whereas under the same conditions it completely blocked  $^{125}\text{I}$ -A $\beta$  binding to ECs.

10 Several cell surface polypeptides/proteoglycans have been previously postulated to interact with A $\beta$ , including SEC, substance P receptors and heparan sulfate proteoglycans, although their role in the pathobiology of AD is not well established. The inability to completely block specific

15 binding of  $^{125}\text{I}$ -A $\beta$  to cortical neurons suggests that these or other binding sites may also be involved, in addition to RAGE. It is important to note that sRAGE, once bound to A $\beta$ , appears to block cellular interactions of amyloid- $\beta$  peptide, whether the latter is present as monomer or under conditions

20 favoring aggregation. This could reflect the size of sRAGE, an  $\mu 30$  kDa polypeptide compared with A $\beta$  ( $\sim 4$  kDa), but it also might be due to binding in the vicinity of A $\beta$  (25-35). It is possible that sRAGE can diminish cellular interactions and toxicity of A $\beta$  deposits by preempting neuronal

25 interactions (with cell surface RAGE and, potentially, other cell surface binding sites) and possibly by limiting assembly of A $\beta$  into aggregates/fibrils. As blocking fibril formation may delay pathologic changes in AD, and as sRAGE-A $\beta$  monomers or smaller aggregates might turn over more

30 rapidly, a detoxification mechanism is suggested.

A $\beta$  is an oxidizing agent, as are AGEs, and such ligands could exert their cellular effects simply as the result of being tethered to RAGE on the cell surface. However, recent

35 studies have shown that stimulation of this receptor by other ligands which do not themselves generate ROIs, induces

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intracellular generation of oxidants in target cells, suggesting that recruitment of signal transduction mechanisms may occur following ligand-RAGE interaction. Further support for an intimate relationship between RAGE and ROIs is the presence of three NF- $\kappa$ B sites in the RAGE promoter whose activity can be triggered by oxidants. These data suggest a possible feedback loop whereby binding of A $\beta$  to RAGE induces oxidant stress which further up-regulates RAGE, thereby augmenting further A $\beta$ -RAGE interaction. The presence of nonenzymatically glycosylated aggregates of A $\beta$ , which has also been shown in AD (Vitek et al., 1994), might additionally facilitate the interaction of extracellular A $\beta$  with RAGE.

Although these studies represent only a first step in establishing a link between expression of RAGE and pathophysiologic changes in AD, they suggest a novel paradigm in which engagement of RAGE has quite different outcomes depending on the nature of the ligand and the microenvironment. During the prenatal and early postnatal period, amphotericin-RAGE interaction promotes neurite outgrowth and supports normal development. In this context, small quantities of soluble A $\beta$ , which exists in normal individuals, might promote neurite outgrowth in association with RAGE. In the vicinity of neuritic plaques, where dystrophic neurites are present, A $\beta$ -RAGE could mediate a repair mechanism or stimulate de novo neurite outgrowth. However, engagement of RAGE on cortical neurons in the presence of higher levels of A $\beta$  in AD, and, by analogy, RAGE binding of AGEs in diabetic vasculature, could result in sustained cellular oxidant stress with deleterious consequences for cellular function and organic homeostasis.

#### Experimental Procedures

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Cell culture, binding assays, and cross-linking studies.

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Murine microvascular endothelial cells (ECs) were used in this studies (Gumkowski et al., 1987). Cultured rat cortical neurons, obtained from neonatal animals and cultured as described previously (Yavin et al., 1974) were  
5 used by day 17. At this time, cultures consisted of >90% neurons based on neurofilament staining. PC12 cells were obtained from ATCC (Rockville MD).

A $\beta$  (1-40), obtained from Quality Controlled Biochemicals  
10 (Hopkinton MA), was dissolved in distilled water (1 mg/ml) and radioiodinated by the Iodobead procedure (Pierce, Rockford IL) as described by the manufacturer. The reaction mixture was desalted by gel filtration, and <sup>125</sup>I-A $\beta$  was >90% precipitable in trichloroacetic acid (20%) and migrated as  
15 a single band with M<sub>r</sub> =4 kDa on tris/tricine gel (16%) electrophoresis. Radioligand binding studies were performed immediately after labelling using endothelial cells and cortical neurons as above. Because of detachment of cortical neurons from the growth substrate during pilot  
20 binding experiments, cultures were briefly exposed to paraformaldehyde (2% for 15 min) prior to the binding studies. Cultures were washed with phosphate-buffered saline (calcium-magnesium-free), followed by addition of binding buffer (minimal essential medium containing bovine  
25 serum albumin-fatty acid free [1%]). Tracer, <sup>125</sup>I-A $\beta$ , was added either alone, in the presence of an 100-fold molar excess of unlabelled A $\beta$  or with one of the reagents listed below, and cultures were incubated (37°C for 2 hrs for neurons and 4°C for 3.5 hrs for ECs) to allow binding. This  
30 incubation time was sufficient for binding to reach an apparent maximum at the lowest tracer concentrations. Unbound ligand was removed by four rapid washes (a total of 6 secs/well); during washing, only a negligible amount of cell-bound ligand dissociated. Elution buffer (NaCl, 0.1 M,  
35 containing Nonidet P-40, 1%) was then added to wells for 5 min at 37°C, and the liquid aspirated and counted. Specific

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binding was defined as total binding (counts observed in wells incubated with  $^{125}\text{I}$ -A $\beta$  alone) minus nonspecific binding (counts observed in wells incubated with  $^{125}\text{I}$ -A $\beta$  in the presence of an 100-fold excess of unlabelled A $\beta$ ).

5 Equilibrium binding data were analyzed according to the equation of Klotz and Hunston (Klotz et al., 1971) using nonlinear least-squares analysis. Where indicated, one of the following was added to binding mixtures: substance P (Sigma), rabbit anti-bovine RAGE IgG (Schmidt et al., 1992),

10 nonimmune rabbit and human IgG (Sigma), recombinant soluble human RAGE, recombinant soluble murine vascular cell adhesion molecule-1 (VCAM-1), antibody to transthyretin (Sigma), and unlabelled A $\beta$ -related peptides (1-40 and 25-35). Note that anti-bovine RAGE IgG has been previously

15 shown to interact with rat, human and bovine RAGE (Brett et al., 1993; Hori et al., 1995). In certain experiments, cells were pretreated with heparin (10  $\mu\text{g}/\text{ml}$  for 30 min), heparanase (2.5 U/ml for 30 min; Sigma; Moscatelli, 1992), or TPCK-treated trypsin (0.05 units/ml for 30 min and serum

20 was added to neutralize trypsin prior to the binding assay with  $^{125}\text{I}$ -A $\beta$ ; Sigma). None of these procedures resulted in cell detachment or loss of viability, based on trypan blue uptake or detachment from the growth substrate. Cross-linking experiments were performed on ECs and neurons

25 (for these studies neurons were not exposed to paraformaldehyde) following binding of  $^{125}\text{I}$ -A $\beta$  to the cell surface by adding disuccinimidyl suberate (DSS; 0.2 mM; Pierce) for 30 min at 25°C. Cultures were then washed twice and dissolved in lysis buffer (NaCl, 0.1 M; NP-40, 1%, PMSF,

30 2 mM, and leupeptin, 10  $\mu\text{g}/\text{ml}$ ) at 4°C for 1 hr. Cellular debris was removed by centrifugation (10,000 rpm for 10 min) and the supernatant was prepared for nonreduced SDS-PAGE (10%).

35 Endothelial cell protein extracts were prepared as described (Schmidt et al., 1992) from  $\sim 10^8$  cells using

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octyl- $\beta$ -glucoside in the presence of protease inhibitors. Binding of  $^{125}$ I-A $\beta$  to proteins in the extract was studied by a previously described method (Schmidt et al., 1992) using an incubation time of 3 hrs at 37°C. Other additions were  
5 as indicated above; note that A $\beta$  (1-20), scrambled A $\beta$  peptide (25-35) was from Quality Controlled Biochemicals, Arg-Gly-Asp-Ser (Seq. I.D. No. 1) was from Sigma, and A $\beta$  purified from AD brain plaque and vasculature was prepared as described (Roher et al., 1993a,b). For certain  
10 experiments, after adsorption of sRAGE to the wells and blocking with albumin, trypsin was added (0.5 units/ml for 1 hr; the initial amount of sRAGE added was 120  $\mu$ g/ml), and neutralization of residual enzyme was as described above.

15 Purification of A $\beta$  binding proteins and characterization of A $\beta$  interaction with RAGE. Acetone extracts of bovine lung and brain (Sigma) were diluted in carbonate/bicarbonate buffer, adsorbed to microtiter wells (as above for endothelial cell extract), and adsorbed proteins studied for  
20 their ability to bind  $^{125}$ I-A $\beta$  by the procedure described above. For purification of A $\beta$  binding proteins, lung extract (100 g) was dissolved in tris-buffered saline containing octyl- $\beta$ -glucoside (1%) and PMSF (2 mM) overnight at 4°C with constant agitation. The mixture was centrifuged  
25 (10,000 rpm for 30 min), applied to Heparin HyperD<sup>®</sup> (bed volume 40 ml; Biosepra), and the column eluted with increasing concentrations of NaCl. Fractions were studied in the microtiter assay for  $^{125}$ I-A $\beta$  binding activity and those with maximal activity were pooled, dialyzed, and then  
30 loaded on hydroxylapatite-ultragel (30 ml bed volume; Biosepra). The column was eluted with increasing concentrations of phosphate, fractions with maximal  $^{125}$ I-A $\beta$  binding activity were identified, pooled and applied to preparative nonreduced SDS-PAGE (10%). Gels were stained  
35 with Coomassie blue, and identical lanes of the gel were either cut into 2 mm slices, protein was eluted and studied



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for A $\beta$  binding activity as above, or slices of the gel were subjected to N-terminal sequence analysis (Hori et al., 1995).

5 A DNA fragment coding for human sRAGE was obtained from a lung library by PCR using human recombinant soluble RAGE was prepared from the human RAGE cDNA (primers: 5'GATGGCAGCCGGAACAGCAGTT3' (Seq. I.D. No. 4) and 5'CTCAAGTTCCTGATCCTCC3') (Seq. I.D. No. 5) and cloned  
10 into the pBacPAK8 vector (Clontech) for expression of recombinant protein as described (Hori et al., 1995). Recombinant sRAGE was purified to homogeneity from Sf9 media by chromatography on SP Sepharose fast flow and Superdex 200PG chromatography as described (Hori et al., 1995)  
15 (Pharmacia) equilibrated with sodium phosphate (20 mM using a baculovirus expression system as described previously for amphoterin (Hori et al., 1995). Antibody was prepared to human recombinant sRAGE by immunizing rabbits according to standard procedures (Vaitukaitis, 1981), and purified IgG  
20 was characterized as monospecific by immunoblotting and ELISA. A DNA fragment coding for the first three immunoglobulin-like domains of VCAM-1 was obtained from a lung cDNA library using PCR (primers: 5'GAAATGCCTGTGAAGATGGTCG3' (Seq. I.D. No. 6) and  
25 5'CTCATTGAACACTAATTCCTCC3') (Seq. I.D. No. 7), expressed and purified as above for sRAGE except that Q Sepharose (Pharmacia) was used (20 mM, pH 8.0).

A $\beta$ -RAGE induced cellular oxidant stress and cytotoxicity.

30 Evidence of A $\beta$ -induced cellular perturbation was studied by evaluating generation of TBARS (Dennery et al., 1990) and reduction of MTT (Promega, Madison WI). In addition, cultures were examined using an inverted Olympus PX-10 microscope. Electrophoretic mobility shift assays (EMSA)  
35 were performed to assess nuclear translocation of NF-kB (Yan et al., 1995). Extracts of nuclear protein were derived

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from cultured cells, as indicated, and reacted with a consensus <sup>32</sup>P-labelled human NF-kB probe.

Immunohistologic studies were performed on paraffin sections of formalin-fixed temporal lobe from AD and age-matched controls (Yan et al., 1995). Sections were first stained with either rabbit anti-human RAGE IgG (20 µg/ml), rabbit anti-human heme oxygenase type I (StressGen, Vancouver Canada), or rabbit anti-human p50 IgG (StressGen), and sites of binding of primary antibody were visualized using the avidin/biotin alkaline phosphatase method. Double staining of these sections for Aβ was performed using murine monoclonal anti-human Aβ IgG (5 µg/ml), followed by peroxidase-conjugated goat anti-mouse IgG. Nonimmune rabbit or mouse IgG were used as controls.

Example 2 : A Receptor Mediating Activation of Microglia by Amyloid-β peptide.

Infiltration of β-amyloid plaques by reactive microglia in Alzheimer's disease (Itagaki et al., 1989; Dickson et al., 1993; and McGeer et al., 1993) as well as β-amyloid induced activation of microglia in vitro (Davis et al., 1992; Klegeris et al., 1994; Meda et al., 1995; and Araujo and Cotman, 1992), suggests that β-amyloid-microglial interaction involves specific pathways. RAGE, an immunoglobulin superfamily receptor previously shown to engage advanced glycation endproducts (Schmidt et al., 1992; and Neeper et al., 1992), serves as a specific binding site for β-amyloid (1-40 and 25-35), and that its expression is enhanced in reactive microglia in Alzheimer's brain. RAGE has a central role in β-amyloid-induced microglial activation: blockade of RAGE prevents binding of <sup>125</sup>I-β-amyloid(1-40) to the cell surface; induction of microglial migration by soluble β-amyloid and arrest of microglia by immobilized β-amyloid are mediated by RAGE; and stimulation of microglial expression of tumor necrosis

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factor- $\alpha$  and activation of NF- $\kappa$ B by  $\beta$ -amyloid is due to binding to RAGE. These data suggest that blockade of  $\beta$ -amyloid-RAGE-dependent microglial activation might prevent triggering of chronic inflammatory cascades in Alzheimer's 5 brain.

The association of activated microglia with amyloid plaques in the brain of patients with Alzheimer's disease (AD) is consistent with an ongoing immune/inflammatory response, as 10 evidenced by microglial expression of the class II major histocompatibility antigen HLA-DR, and cytokines, such as Interleukins 1 and 6 (Dickson et al., 1993; and McGeer et al., 1993). That changes in microglial activation might be a direct consequence of  $\beta$ -amyloid (A $\beta$ )-microglial 15 interaction is supported by the observation that soluble A $\beta$ (1-40 and 25-35) promotes microglial chemotaxis, as well as TNF, Interleukin 1 $\beta$ , and basic fibroblast growth factor expression and nitrite production (Davis et al., 1992; Klegeris et al., 1994; Meda et al., 1995; and Araujo and 20 Cotman, 1992). Recently it has been found that RAGE, Receptor for Advanced Glycation Endproducts (Schmidt et al., 1992; and Neeper et al., 1992), binds A $\beta$ (1-40 and 25-35) in a specific, dose-dependent, and saturable manner ( $K_d$   $\mu$ 55 nM); and A $\beta$ -RAGE interaction mediates, at least in part, neuronal 25 cytotoxicity and oxidant stress due to A $\beta$  (Yan et al., 1996). As RAGE is expressed by mononuclear phagocytes (Schmidt et al., 1993), we sought its presence in activated microglia in AD brain. Microglia, identified by staining with CD68 (Fig. 8A), proximate to a senile plaque, show 30 strong expression of RAGE antigen (Fig. 8B).

Radioligand binding studies with BV-2 cells demonstrated dose-dependent binding of  $^{125}$ I-A $\beta$ (1-40) with  $K_d$   $\approx$ 30nM (Fig. 9A). Blockade of RAGE, with either excess sRAGE or 35 anti-RAGE IgG, prevented binding of  $^{125}$ I-A $\beta$  to microglia, although soluble vascular cell adhesion molecule-1 (another

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immunoglobulin superfamily molecule) or nonimmune rabbit IgG was without effect (Fig. 9B).

As RAGE appeared to have a central role in tethering A $\beta$  to microglia, it was considered whether A $\beta$ -RAGE interaction might underlie A $\beta$ -induced migration of microglia. Using BV-2 cells, addition of A $\beta$  (1-40 or 25-35) to microchemotaxis chambers resulted in directional cell migration, dependent on a concentration gradient of the stimulus from upper to lower chamber (Fig. 10A). Cell migration was prevented by addition of anti-RAGE F(ab')<sub>2</sub>, whereas this reagent had no effect on motility of BV-2 cells following addition of formylated peptide (formyl-methionyl-leucyl phenylalanine, fMLP) (Fig. 10B). In contrast, nonimmune rabbit IgG was without effect on A $\beta$ -induced migration of BV-2 cells. Because of the known accumulation of microglia approximate to deposits of A $\beta$ , it was possible that, in contrast to soluble A $\beta$ , immobilized A $\beta$  might block microglial migration. To test this concept, either A $\beta$  or albumin was adsorbed to the upper surface of chemotaxis chamber membranes and BV-2 cells were added; cell migration across A $\beta$ -coated membranes was diminished in response to a range of fMLP concentrations added to the lower compartment, whereas albumin-coated membranes allowed free passage of cells (Fig. 10C), comparable to untreated membranes. Blockade of RAGE with anti-RAGE F(ab')<sub>2</sub> enhanced BV-2 migration across A $\beta$ -coated membranes to levels observed in membranes coated with albumin, whereas nonimmune F(ab')<sub>2</sub> was without effect. Similar results were observed in a more limited number of studies on microglia isolated from rat brain). These data indicate that soluble A $\beta$  induces microglial migration whereas immobilized A $\beta$  arrests microglial migration, in each case due to A $\beta$  engagement of RAGE.

35

Activation of microglia, potentially producing cytotoxic

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cytokines and other species (Dickson et al., 1993; McGeer et al., 1993; Meda et al., 1995; and Araujo et al., 1992), may be an important pathway to neuronal damage in AD. Of these, the ability of A $\beta$  to stimulate microglial expression of tumor necrosis factor- $\alpha$  (TNF $\alpha$ ) (Meda et al., 1995) may be especially significant, as TNF $\alpha$  could recruit additional host effector mechanisms. BV-2 cells incubated with A $\beta$  demonstrated induction of TNF $\alpha$  transcripts by PCR (Fig. 11A), followed by elaboration of TNF $\alpha$  into culture supernatants (Fig. 11B). Blockade of RAGE, with anti-RAGE F(ab')<sub>2</sub>, prevented the appearance of TNF $\alpha$  mRNA and diminished TNF $\alpha$  antigen to levels seen in untreated cells, whereas nonimmune F(ab')<sub>2</sub>. A mechanism through which A $\beta$  and other cytokines influence cellular activation is by inducing nuclear translocation of the transcription factor NF- $\kappa$ B, often utilizing an oxidant-mediated pathway (Schreck et al., 1991). Incubation of BV-2 cells with microglia induced NF- $\kappa$ B activation which was suppressed by blocking RAGE with anti-RAGE F(ab')<sub>2</sub> (Fig. 11C) or the antioxidant probucol. Nonimmune F(ab')<sub>2</sub> was without effect.

These data show that RAGE has a pivotal role in the interaction of A $\beta$  with microglial cells. Soluble A $\beta$  binds RAGE and induces microglial migration along a concentration gradient, likely to end at a deposit of insoluble A $\beta$ . Immobilized A $\beta$  (prepared as above or after allowing time for fibrils of A $\beta$  to form) prevents cell migration, permitting microglia to undergo the sustained activation which may underlie a chronic inflammatory component in AD (Rogers et al., 1993; and Breitner et al., 1994). Indeed, in some studies it was found that immobilized A $\beta$  does induce microglial activation, and the time course for TNF production is more prolonged than that observed following exposure of microglia to soluble A $\beta$ . Although these data indicate that RAGE is important in mediating microglial binding and subsequent cellular activation following

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exposure to A $\beta$ , in view of the number of different polypeptides with which A $\beta$  has been shown to interact (Iversen et al., 1995), it is likely that other proteins will also be identified which participate with RAGE in A $\beta$ -mediated cellular activation. In this context, these studies have emphasized the potential of A $\beta$ -RAGE interaction to activate microglia, accelerating events leading to neurodegeneration. However, RAGE processing of A $\beta$  (i.e., endocytosis and degradation), under conditions where substantial amounts of A $\beta$  are present probably represents a protective mechanism gone awry: it is possible that small amounts of A $\beta$  might be endocytosed and degraded by RAGE-dependent mechanisms, whereas larger amounts of peptide might overwhelm this mechanism and result in A $\beta$ -RAGE-induced cellular activation. These studies complement the recent observation that RAGE is expressed at higher levels in neurons approximate to A $\beta$  deposits (Yan et al., 1996). RAGE appears to mediate oxidant stress and neurotoxicity, as shown by their attenuation following blockade of the receptor (Yan et al., 1996). The possibility that A $\beta$  in AD is subject to nonenzymatic glycation with formation of advanced glycation endproducts (the latter were the first recognized ligands of RAGE) provides an additional mechanism for enhancing its interaction with RAGE (Vitek et al., 1994). Taken together, these observations suggest that increased expression of RAGE in AD brain may have a central role in A $\beta$ -mediated microglial activation, as well as neuronal perturbation. Thus, interfering with A $\beta$ -RAGE interaction might delay the development of subsequent cellular events resulting in neuronal dysfunction.

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20

-48-

## SEQUENCE LISTING

## (1) GENERAL INFORMATION:

- (i) APPLICANT: Stern, David  
Schmidt, Ann Marie  
Yan, Shi Du
- (ii) TITLE OF INVENTION: A POLYPEPTIDE FROM LUNG EXTRACT WHICH  
BINDS AMYLOID-BETA PEPTIDE
- (iii) NUMBER OF SEQUENCES: 10
- (iv) CORRESPONDENCE ADDRESS:
  - (A) ADDRESSEE: Cooper & Dunham LLP
  - (B) STREET: 1185 Avenue of the Americas
  - (C) CITY: New York
  - (D) STATE: New York
  - (E) COUNTRY: U.S.A.
  - (F) ZIP: 10036
- (v) COMPUTER READABLE FORM:
  - (A) MEDIUM TYPE: Floppy disk
  - (B) COMPUTER: IBM PC compatible
  - (C) OPERATING SYSTEM: PC-DOS/MS-DOS
  - (D) SOFTWARE: PatentIn Release #1.0, Version #1.30
- (vi) CURRENT APPLICATION DATA:
  - (A) APPLICATION NUMBER:
  - (B) FILING DATE: 26-JAN-1996
  - (C) CLASSIFICATION:
- (viii) ATTORNEY/AGENT INFORMATION:
  - (A) NAME: White, John P.
  - (B) REGISTRATION NUMBER: 28,678
  - (C) REFERENCE/DOCKET NUMBER: 48316
- (ix) TELECOMMUNICATION INFORMATION:
  - (A) TELEPHONE: 212-278-0400
  - (B) TELEFAX: 212-391-0526

## (2) INFORMATION FOR SEQ ID NO:1:

- (i) SEQUENCE CHARACTERISTICS:
  - (A) LENGTH: 4 amino acids
  - (B) TYPE: amino acid
  - (C) STRANDEDNESS: single
  - (D) TOPOLOGY: linear

(ii) MOLECULE TYPE: peptide

## (xi) SEQUENCE DESCRIPTION: SEQ ID NO:1:

Arg Gly Asp Ser  
1

## (2) INFORMATION FOR SEQ ID NO:2:

- (i) SEQUENCE CHARACTERISTICS:

-49-

- (A) LENGTH: 40 amino acids
- (B) TYPE: amino acid
- (C) STRANDEDNESS: single
- (D) TOPOLOGY: linear

(ii) MOLECULE TYPE: peptide

(xi) SEQUENCE DESCRIPTION: SEQ ID NO:2:

Asp Ala Glu Phe Arg His Asp Ser Gly Tyr Glu Val His His Gln Lys  
1 5 10 15  
Leu Val Phe Phe Ala Glu Asp Val Gly Ser Asn Lys Gly Ala Ile Ile  
20 25 30  
Gly Leu Met Val Gly Gly Val Val  
35 40

(2) INFORMATION FOR SEQ ID NO:3:

- (i) SEQUENCE CHARACTERISTICS:
  - (A) LENGTH: 11 amino acids
  - (B) TYPE: amino acid
  - (C) STRANDEDNESS: single
  - (D) TOPOLOGY: linear

(ii) MOLECULE TYPE: peptide

(xi) SEQUENCE DESCRIPTION: SEQ ID NO:3:

Gly Ser Asn Lys Gly Ala Ile Ile Gly Leu Met  
1 5 10

(2) INFORMATION FOR SEQ ID NO:4:

- (i) SEQUENCE CHARACTERISTICS:
  - (A) LENGTH: 22 base pairs
  - (B) TYPE: nucleic acid
  - (C) STRANDEDNESS: single
  - (D) TOPOLOGY: linear

(ii) MOLECULE TYPE: DNA (genomic)

(xi) SEQUENCE DESCRIPTION: SEQ ID NO:4:

GATGGCAGCC GGAACAGCAG TT  
22

(2) INFORMATION FOR SEQ ID NO:5:

- (i) SEQUENCE CHARACTERISTICS:
  - (A) LENGTH: 25 base pairs
  - (B) TYPE: nucleic acid
  - (C) STRANDEDNESS: single
  - (D) TOPOLOGY: linear

-50-

(ii) MOLECULE TYPE: DNA (genomic)

(xi) SEQUENCE DESCRIPTION: SEQ ID NO:5:

CTCAAGTTCC CAGCCCTGAT CCTCC  
25

(2) INFORMATION FOR SEQ ID NO:6:

(i) SEQUENCE CHARACTERISTICS:  
(A) LENGTH: 22 base pairs  
(B) TYPE: nucleic acid  
(C) STRANDEDNESS: single  
(D) TOPOLOGY: linear

(ii) MOLECULE TYPE: DNA (genomic)

(xi) SEQUENCE DESCRIPTION: SEQ ID NO:6:

GAAATGCCTG TGAAGATGGT CG  
22

(2) INFORMATION FOR SEQ ID NO:7:

(i) SEQUENCE CHARACTERISTICS:  
(A) LENGTH: 24 base pairs  
(B) TYPE: nucleic acid  
(C) STRANDEDNESS: single  
(D) TOPOLOGY: linear

(ii) MOLECULE TYPE: DNA (genomic)

(xi) SEQUENCE DESCRIPTION: SEQ ID NO:7:

CTCATTGAAC ACTAATTCCA CTC  
24

(2) INFORMATION FOR SEQ ID NO:8:

(i) SEQUENCE CHARACTERISTICS:  
(A) LENGTH: 30 amino acids  
(B) TYPE: amino acid  
(C) STRANDEDNESS: single  
(D) TOPOLOGY: linear

(ii) MOLECULE TYPE: peptide

(xi) SEQUENCE DESCRIPTION: SEQ ID NO:8:

Asp Gln Asn Ile Thr Ala Arg Ile Gly Lys Pro Leu Val Leu Asn Cys  
1 5 10 15

-51-

Lys Gly Ala Pro Lys Lys Pro Pro Gln Gln Leu Glu Trp Lys  
                   20                                  25                                  30

## (2) INFORMATION FOR SEQ ID NO:9:

- (i) SEQUENCE CHARACTERISTICS:  
 (A) LENGTH: 30 amino acids  
 (B) TYPE: amino acid  
 (C) STRANDEDNESS: single  
 (D) TOPOLOGY: linear

(ii) MOLECULE TYPE: peptide

## (xi) SEQUENCE DESCRIPTION: SEQ ID NO:9:

Asp Gln Xaa Ile Thr Ala Arg Ile Gly Lys Pro Leu Val Leu Asn Xaa  
   1                  5                                  10                                  15

Lys Gly Ala Pro Lys Lys Pro Pro Gln Gln Leu Glu Trp Lys  
                   20                                  25                                  30

## (2) INFORMATION FOR SEQ ID NO:10:

- (i) SEQUENCE CHARACTERISTICS:  
 (A) LENGTH: 20 amino acids  
 (B) TYPE: amino acid  
 (C) STRANDEDNESS: single  
 (D) TOPOLOGY: linear

(ii) MOLECULE TYPE: peptide

## (xi) SEQUENCE DESCRIPTION: SEQ ID NO:10:

Asp Gln Xaa Ile Thr Ala Arg Ile Gly Lys Pro Leu Val Leu Asn Xaa  
   1                  5                                  10                                  15

Lys Gly Ala Pro  
                   20

What is claimed is:

1. A method for inhibiting interaction of an amyloid- $\beta$  peptide with a receptor for advanced glycation end product on the surface of a cell which comprises  
5 contacting the cell with an agent capable of inhibiting interaction of the amyloid- $\beta$  peptide with the receptor for advanced glycation end product, the agent being present in an amount effective to inhibit interaction  
10 of the amyloid- $\beta$  peptide with the receptor for advanced glycation end product on the surface of the cell.
2. The method of claim 1, wherein the cell is a neuronal cell, an endothelial cell, a glial cell, a microglial  
15 cell, a smooth muscle cell, a somatic cell, a bone marrow cell, a liver cell, an intestinal cell, a germ cell, a myocyte, a mononuclear phagocyte, an endothelial cell, a tumor cell, or a stem cell.
- 20 3. The method of claim 1, wherein the agent is a peptide, a peptidomimetic, a nucleic acid or a small molecule.
4. The method of claim 3, wherein the peptide comprises at least a portion of the sequence -Asp-Ala-Glu-Phe-Arg-  
25 His-Asp-Ser-Gly-Tyr-Glu-Val-His-His-Gln-Lys-Leu-Val-Phe-Phe-Ala-Glu-Asp-Val-Gly-Ser-Asn-Lys-Gly-Ala-Ile-Ile-Gly-Leu-Met-Val-Gly-Gly-Val-Val- (Seq. I.D. No. 2).
5. The method of claim 3, wherein the peptide comprises at least a portion of the sequence -Gly-Ser-Asn-Lys-Gly-  
30 Ala-Ile-Ile-Gly-Leu-Met- (Seq. I.D. No. 3).
6. The method of claim 1, wherein the agent is soluble receptor for advanced glycation end product.
- 35 7. The method of claim 1, wherein the agent is a soluble

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extracellular portion of a receptor for advanced glycation end product.

8. The method of claim 1, wherein the agent is an antibody  
5 or portion thereof.
9. The method of claim 8, wherein the antibody is capable  
of specifically binding to the receptor for advanced  
glycation endproduct.  
10
10. The method of claim 8, wherein the antibody is a  
monoclonal antibody.
11. The method of claim 8, wherein the antibody is a  
15 polyclonal antibody.
12. The method of claim 8, wherein the portion of the  
antibody comprises a Fab.
- 20 13. The method of claim 8, wherein the portion of the  
antibody comprises a complementarity determining region  
or a variable region.
14. The method of claim 1, wherein the agent is capable of  
25 specifically binding to the amyloid- $\beta$  peptide.
15. The method of claim 14, wherein the agent binds to the  
amyloid- $\beta$  peptide at the site where the receptor for  
advanced glycation end product interacts.  
30
16. A method for inhibiting degeneration of a neuronal cell  
which comprises contacting the cell with an agent  
capable of inhibiting interaction of an amyloid- $\beta$   
peptide with a receptor for advanced glycation end  
35 product on the surface of the neuronal cell according  
to the method of claim 1.

17. A method for inhibiting formation of an amyloid- $\beta$  peptide fibril on a cell which comprises contacting the cell with an agent capable of inhibiting interaction of  
5 an amyloid- $\beta$  peptide with a receptor for advanced glycation end product on the surface of the cell according to the method of claim 1.
18. A method for inhibiting extracellular assembly of an  
10 amyloid- $\beta$  peptide into a fibril which comprises contacting the amyloid- $\beta$  peptide with an agent capable of inhibiting interaction of an amyloid- $\beta$  peptide with another amyloid- $\beta$  peptide according to the method of claim 1.
- 15 19. A method for inhibiting aggregation of amyloid- $\beta$  peptide on the surface of a cell which comprises contacting the amyloid- $\beta$  peptide with an agent capable of inhibiting interaction of the amyloid- $\beta$  peptide with  
20 a receptor for advanced glycation end product according to the method of claim 1.
20. A method for inhibiting aggregation of amyloid- $\beta$  peptide on the surface of a cell which comprises  
25 contacting the receptor for advanced glycation end product with an agent capable of inhibiting interaction of the amyloid- $\beta$  peptide with the receptor for advanced glycation end product according to the method of claim 1.
- 30 21. A method for inhibiting infiltration of a microglial cell into senile plaques which comprises contacting the microglial cell with an agent capable of inhibiting interaction of an amyloid- $\beta$  peptide with a receptor for  
35 advanced glycation end product on the surface of the microglial cell according to the method of claim 1.



22. A method for inhibiting activation of a microglial cell by an amyloid- $\beta$  peptide which comprises contacting the microglial cell with an agent capable of inhibiting  
5 interaction of the amyloid- $\beta$  peptide with a receptor for advanced glycation end product on the surface of the microglial cell according to the method of claim 1.
23. The method of claim 22, wherein the inhibition of  
10 activation comprises decreased production of cytokines by the microglial cell.
24. The method of claim 1, wherein the interaction is binding of the amyloid- $\beta$  peptide to the receptor for  
15 advanced glycation end product on the surface of the cell.
25. A method for treating a subject with a condition associated with interaction of an amyloid- $\beta$  peptide  
20 with a receptor for advanced glycation end product on a cell, which comprises administering to the subject an agent capable of inhibiting the interaction of the amyloid- $\beta$  peptide with the receptor for advanced glycation end product, the agent being present in an  
25 amount effective to inhibit the amyloid- $\beta$  peptide interaction with the receptor for advanced glycation end product on the cell thereby treating the subject.
26. The method of claim 25, wherein the condition is  
30 diabetes, Alzheimer's Disease, senility, renal failure, hyperlipidemic atherosclerosis, neuronal cytotoxicity, Down's syndrome, dementia associated with head trauma, amyotrophic lateral sclerosis, multiple sclerosis or neuronal degeneration.
- 35 27. The method of claim 25, wherein the subject is a

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mammal.

28. The method of claim 27, wherein the mammal is a human.
- 5 29. The method of claim 25, wherein the administration comprises intralesional, intraperitoneal, intramuscular or intravenous injection; infusion; liposome-mediated delivery; topical, nasal, oral, anal, ocular or otic delivery.
- 10 30. The method of claim 25, wherein the agent is soluble receptor for advanced glycation end product.
- 15 31. The method of claim 25, wherein the agent is a soluble extracellular portion of a receptor for advanced glycation end product.
- 20 32. The method of claim 25, wherein the agent is a peptide, a peptidomimetic, a nucleic acid or a small molecule.
33. The method of claim 32, wherein the peptide comprises at least a portion of the sequence -Asp-Ala-Glu-Phe-Arg-His-Asp-Ser-Gly-Tyr-Glu-Val-His-His-Gln-Lys-Leu-Val-Phe-Phe-Ala-Glu-Asp-Val-Gly-Ser-Asn-Lys-Gly-Ala-Ile-Ile-Gly-Leu-Met-Val-Gly-Gly-Val-Val- (Seq. I.D. No. 2).
- 25 34. The method of claim 32, wherein the peptide comprises at least a portion of the sequence -Gly-Ser-Asn-Lys-Gly-Ala-Ile-Ile-Gly-Leu-Met- (Seq. I.D. No. 3).
- 30 35. The method of claim 25, wherein the agent is an antibody or portion thereof.
- 35 36. The method of claim 35, wherein the antibody is capable of specifically binding to the receptor for advanced

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glycation endproduct.

37. The method of claim 35, wherein the antibody is a monoclonal antibody.
- 5 38. The method of claim 35, wherein the antibody is a polyclonal antibody.
- 10 39. The method of claim 35, wherein the portion of the antibody comprises a Fab.
40. The method of claim 35, wherein the portion of the antibody comprises a complementarity determining region or a variable region.
- 15 41. The method of claim 25, wherein the agent is capable of specifically binding to the amyloid- $\beta$  peptide.
- 20 42. The method of claim 41, wherein the agent binds to the amyloid- $\beta$  peptide at the site where the receptor for advanced glycation end product interacts.
- 25 43. The method of claim 25, wherein the condition is associated with degeneration of a neuronal cell in the subject.
44. The method of claim 25, wherein the condition is associated with formation of an amyloid- $\beta$  peptide fibril.
- 30 45. The method of claim 25, wherein the condition is associated with aggregation of amyloid- $\beta$  peptide.
- 35 46. The method of claim 25, wherein the condition is associated with infiltration of a microglial cell into a senile plaque.

47. The method of claim 25, wherein the condition is associated with activation of a microglial cell by an amyloid- $\beta$  peptide.
- 5 48. The method of claim 47, wherein the activation comprises production of cytokines by the microglial cell.
- 10 49. A method for evaluating the ability of an agent to inhibit binding of an amyloid- $\beta$  peptide with a receptor for advanced glycation end product on the surface of a cell which comprises:
- 15 (a) contacting the cell with the agent and amyloid- $\beta$  peptide;
- (b) determining the amount of amyloid- $\beta$  peptide bound to the cell, and
- 20 (c) comparing the amount of bound amyloid- $\beta$  peptide determined in step (b) with the amount determined in the absence of the agent, thus evaluating the ability of the agent to inhibit the binding of
- 25 amyloid- $\beta$  peptide to the receptor for advanced glycation end product on the surface of the cell.
50. The method of claim 49, wherein the cell is contacted with the agent and the amyloid- $\beta$  peptide
- 30 simultaneously.
51. The method of claim 49, wherein the cell is contacted with the amyloid- $\beta$  peptide and the agent.
- 35 52. The method of claim 49, wherein the cell is a neuronal cell, an endothelial cell, a glial cell, a microglial

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cell, a smooth muscle cell, a somatic cell, a bone marrow cell, a liver cell, an intestinal cell, a germ cell, a myocyte, a mononuclear phagocyte, an endothelial cell, a tumor cell, or a stem cell.

5

53. The method of claim 49, wherein the agent is a peptide, a peptidomimetic, a nucleic acid or a small molecule.

54. The method of claim 53, wherein the peptide comprises  
10 at least a portion of the sequence -Asp-Ala-Glu-Phe-Arg-His-Asp-Ser-Gly-Tyr-Glu-Val-His-His-Gln-Lys-Leu-Val-Phe-Phe-Ala-Glu-Asp-Val-Gly-Ser-Asn-Lys-Gly-Ala-Ile-Ile-Gly-Leu-Met-Val-Gly-Gly-Val-Val- (Seq. I.D. No. 2).

15

55. The method of claim 53, wherein the peptide comprises at least a portion of the sequence -Gly-Ser-Asn-Lys-Gly-Ala-Ile-Ile-Gly-Leu-Met- (Seq. I.D. No. 3).

20 56. The method of claim 49, wherein the agent is soluble receptor for advanced glycation end product.

57. The method of claim 49, wherein the agent is a soluble  
25 extracellular portion of receptor for advanced glycation end product.

58. The method of claim 49, wherein the agent is an antibody or portion thereof.

30 59. The method of claim 58, wherein the antibody is capable of specifically binding to the receptor for advanced glycation endproduct.

60. The method of claim 58, wherein the antibody is a  
35 monoclonal antibody.

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61. The method of claim 58, wherein the antibody is a polyclonal antibody.
62. The method of claim 58, wherein the portion of the  
5 antibody comprises a Fab.
63. The method of claim 58, wherein the portion of the antibody comprises a complementarity determining region or a variable region.
- 10 64. The method of claim 49, wherein the agent is capable of specifically binding to the amyloid- $\beta$  peptide.
65. The method of claim 64, wherein the agent binds to  
15 amyloid- $\beta$  peptide at the site where the receptor for advanced glycation end product interacts.
66. The method of claim 49, wherein the agent is a soluble extracellular portion of a receptor for advanced  
20 glycation end product.
67. The method of claim 49, wherein the agent is bound to a solid support.
- 25 68. The method of claim 49, wherein the agent is expressed on the surface of a cell.
69. A method for inhibiting activation of an NF- $\kappa$ B gene in a cell which comprises contacting the cell with an  
30 agent which is capable of inhibiting interaction of amyloid- $\beta$  peptide with a receptor for advanced glycation endproduct on the cell, thus inhibiting activation of NF- $\kappa$ B in the cell.
- 35 70. A pharmaceutical composition which comprises an agent capable of inhibiting interaction of amyloid- $\beta$  peptide

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with a receptor for advanced glycation endproduct and a pharmaceutically acceptable carrier.

71. The pharmaceutical composition of claim 70, wherein the carrier is a diluent, an aerosol, a topical carrier, an aqueous solution, a nonaqueous solution or a solid carrier.

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FIG. 1A

FIG. 1B

FIG. 1C

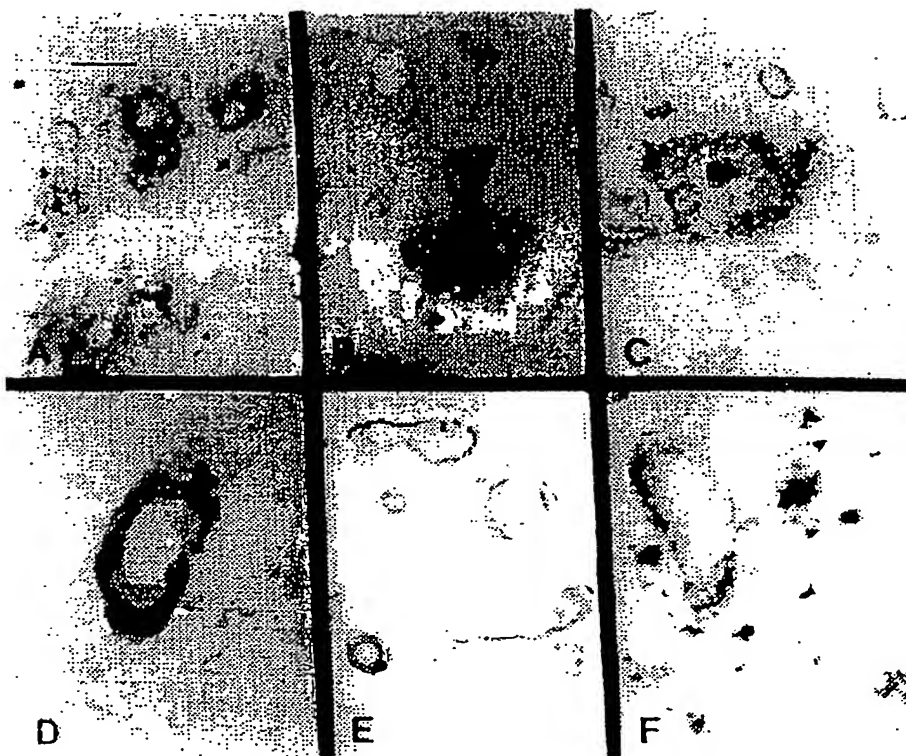


FIG. 1D

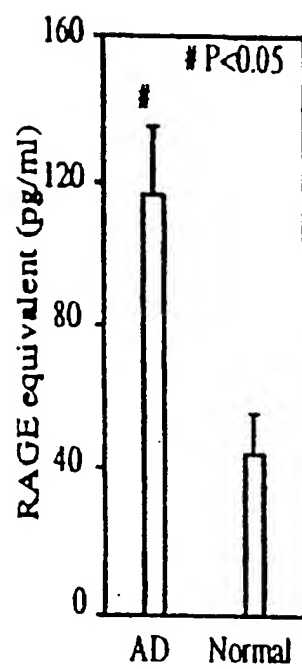
FIG. 1E

FIG. 1F



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FIG. 1G



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FIG. 2A

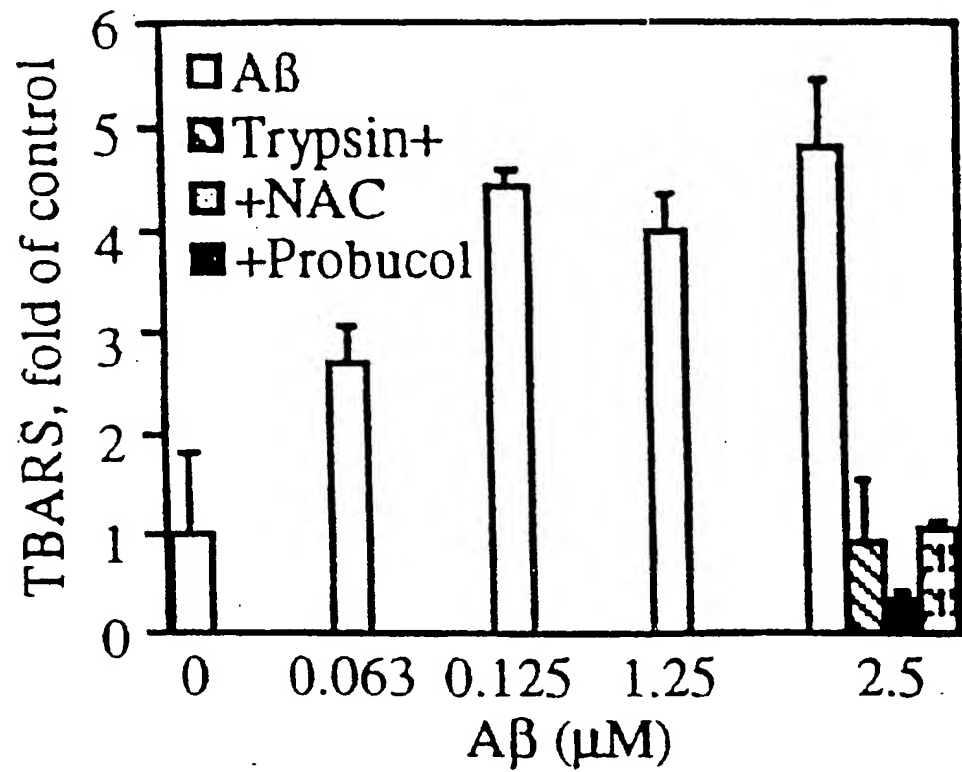
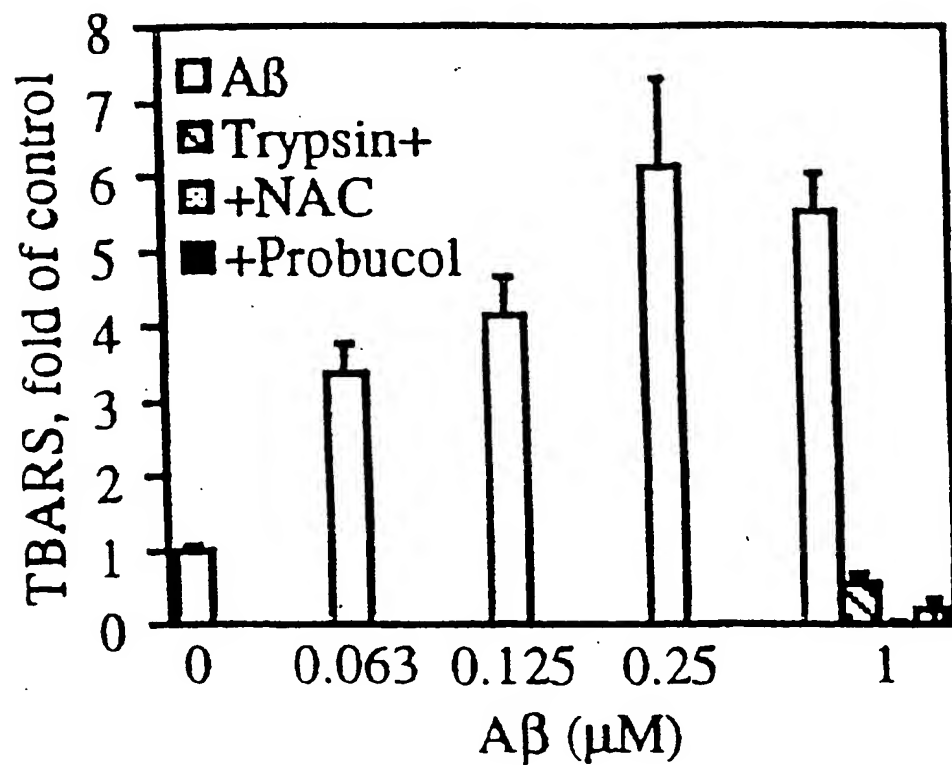


FIG. 2B



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FIG. 2C-1

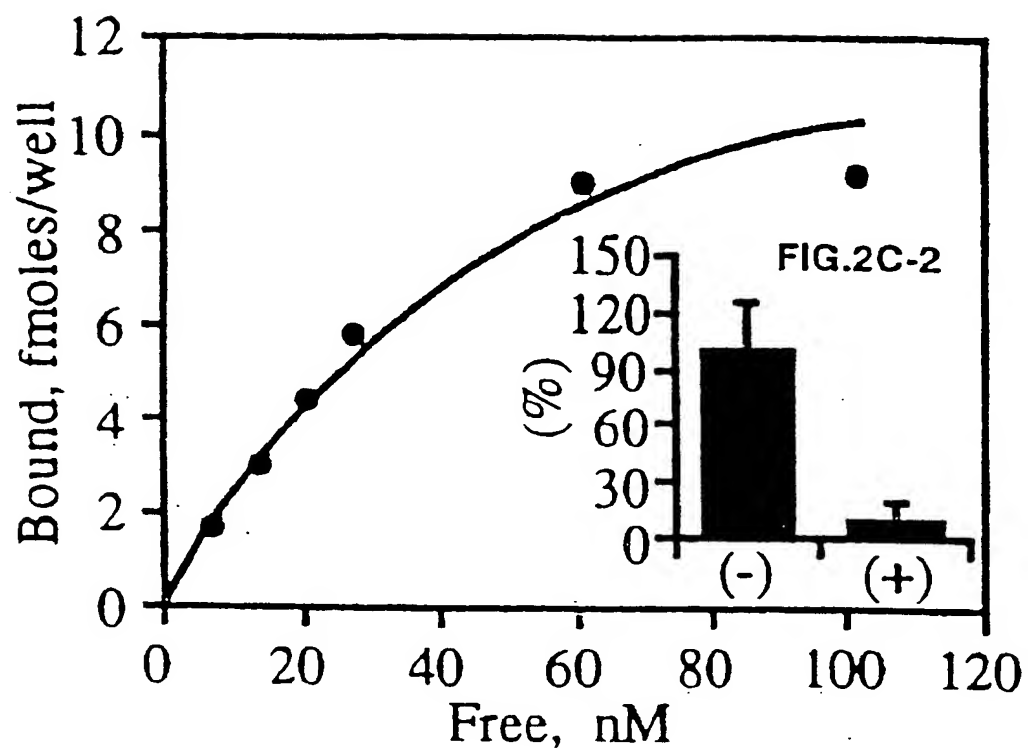
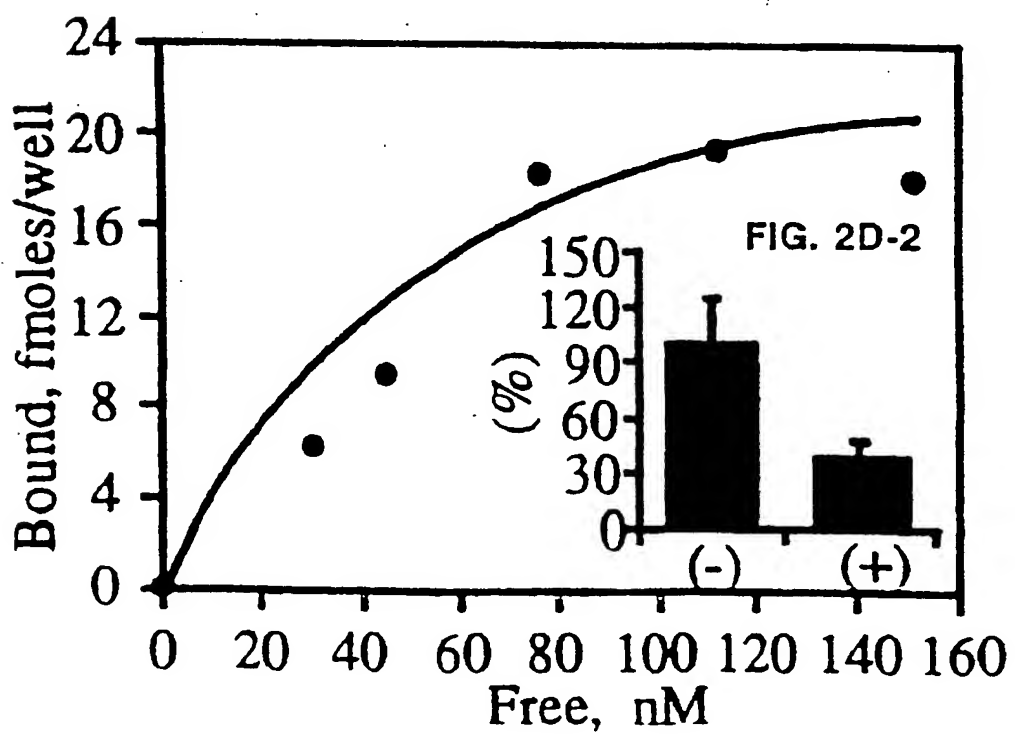


FIG. 2D-1



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FIG. 2E

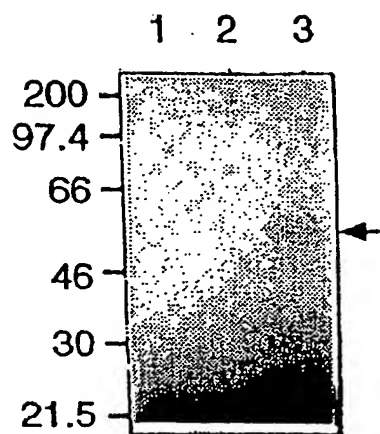
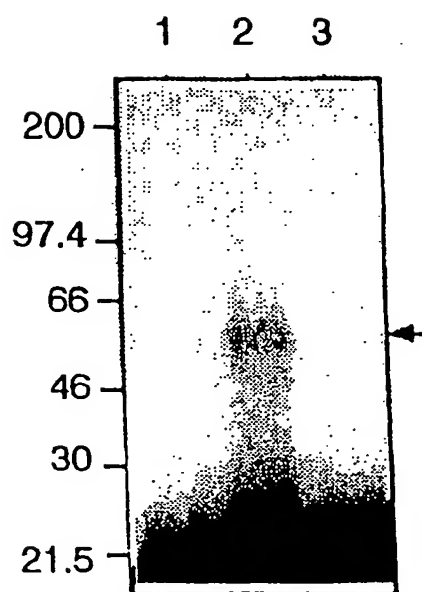


FIG. 2F



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FIG. 3A

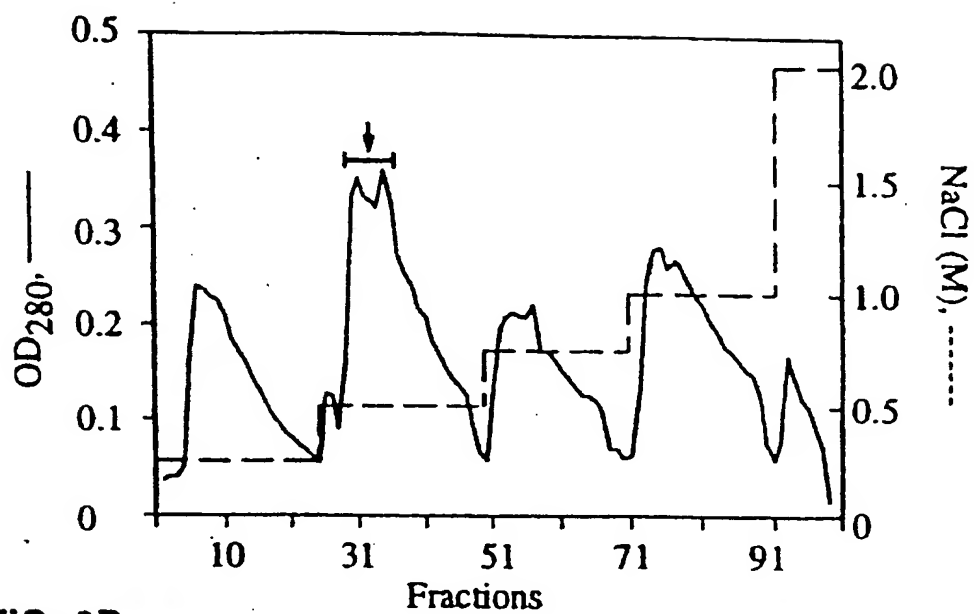
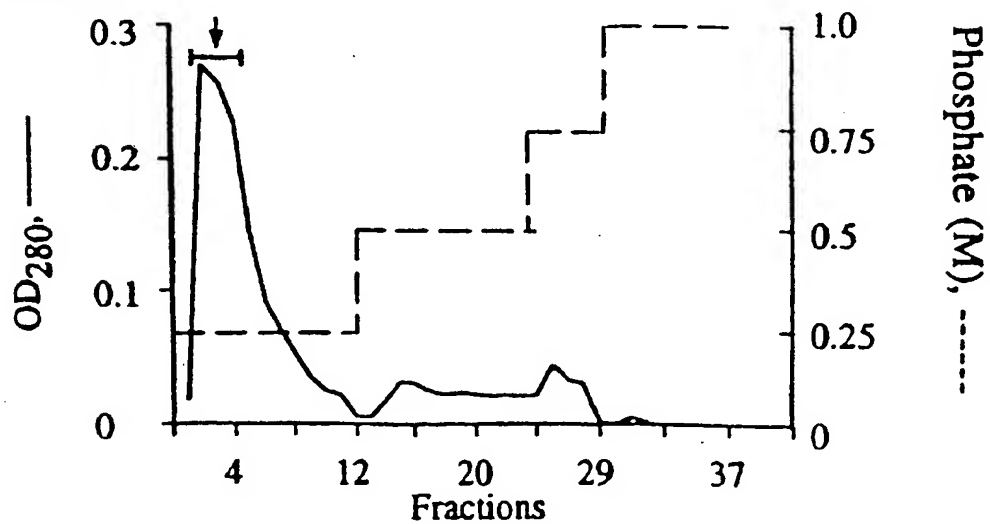
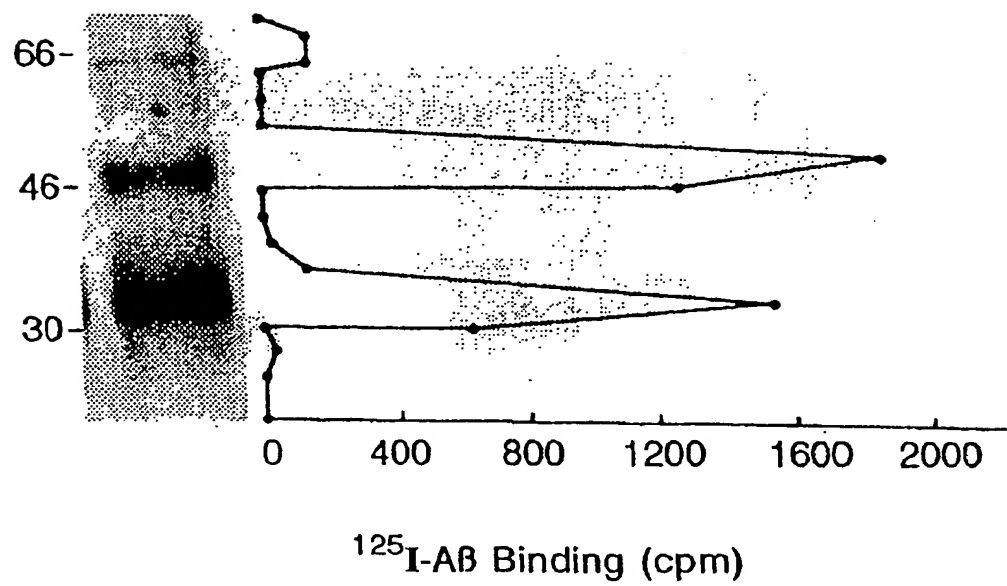


FIG. 3B



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FIG. 3C

 $^{125}\text{I}$ -AB Binding (cpm)

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FIG. 4A

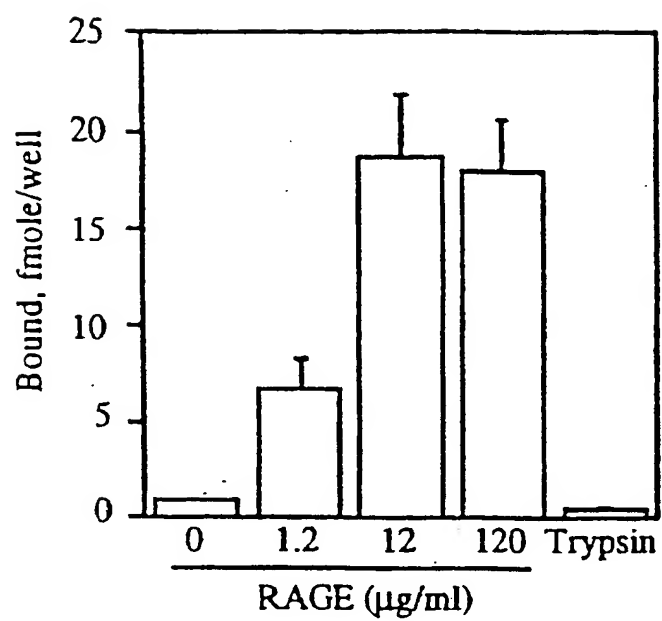
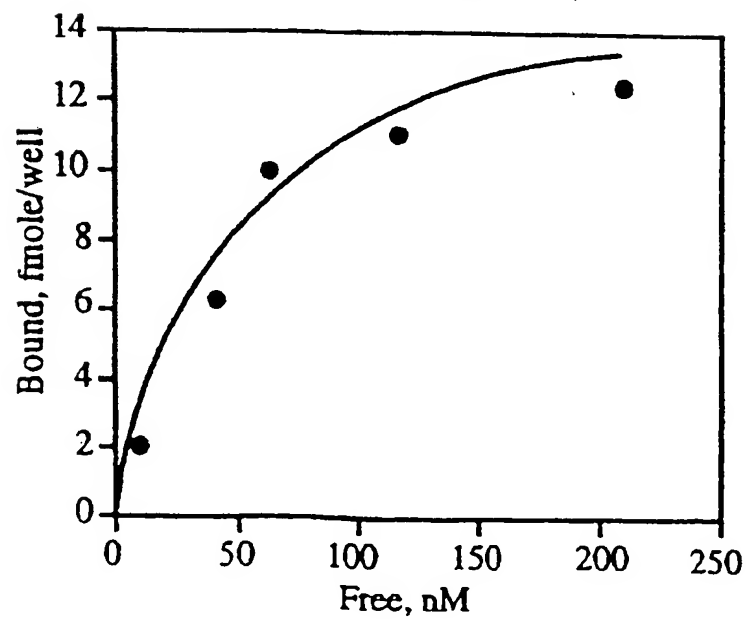


FIG. 4B



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FIG. 4C

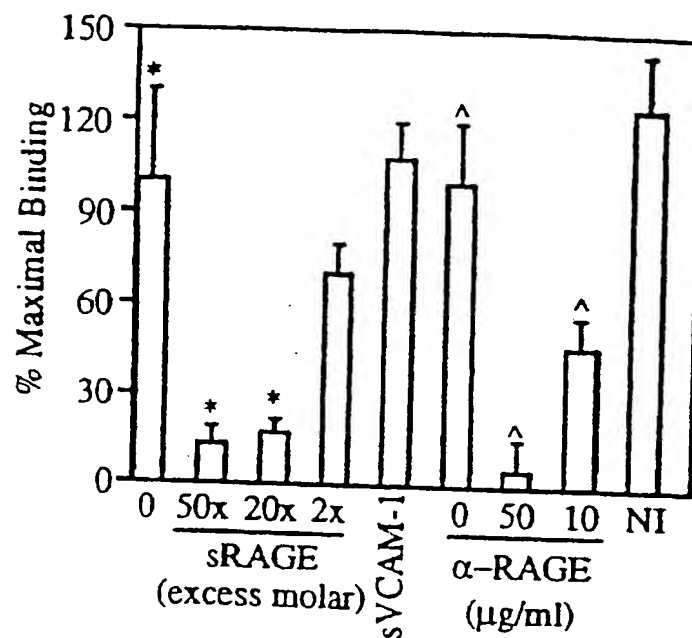
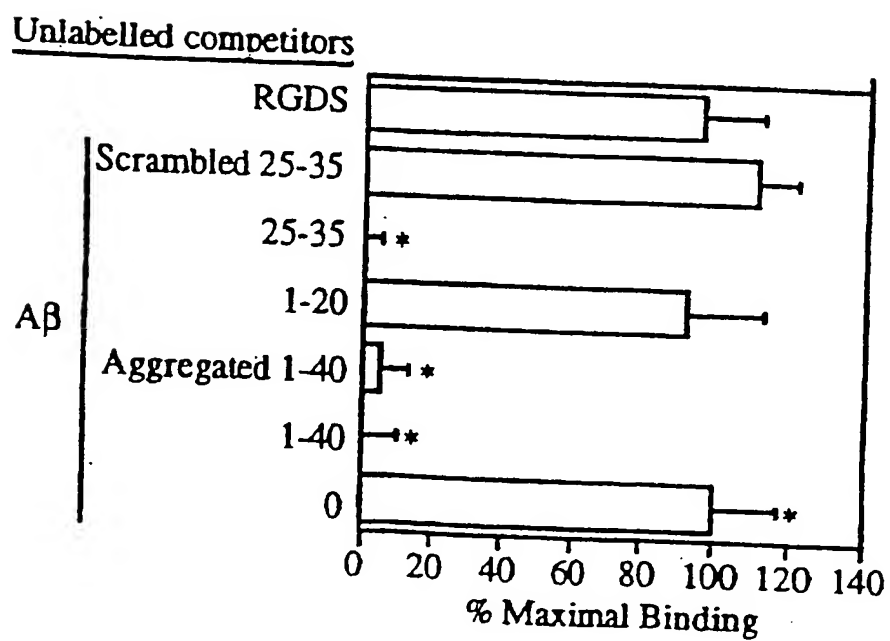


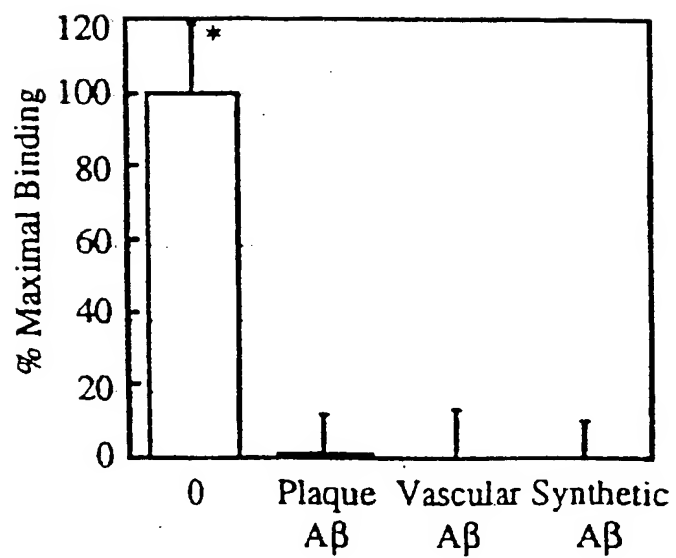
FIG. 4D





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FIG. 4E



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FIG. 5A

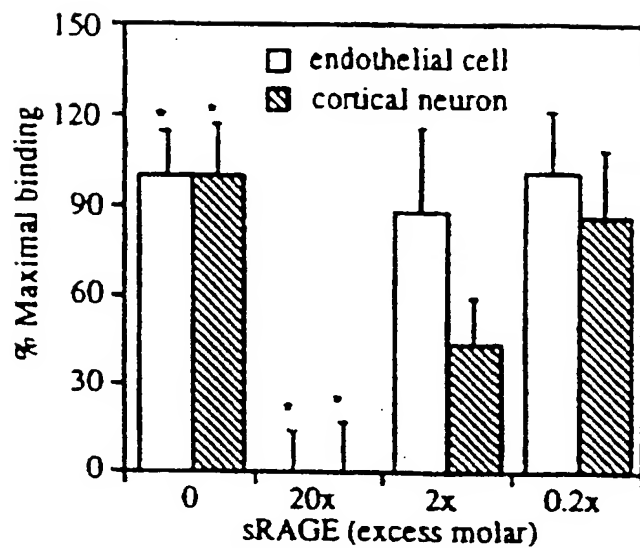


FIG. 5B

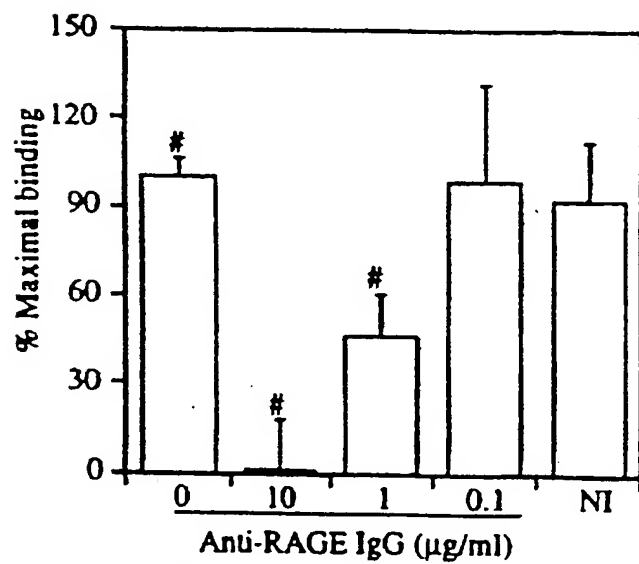
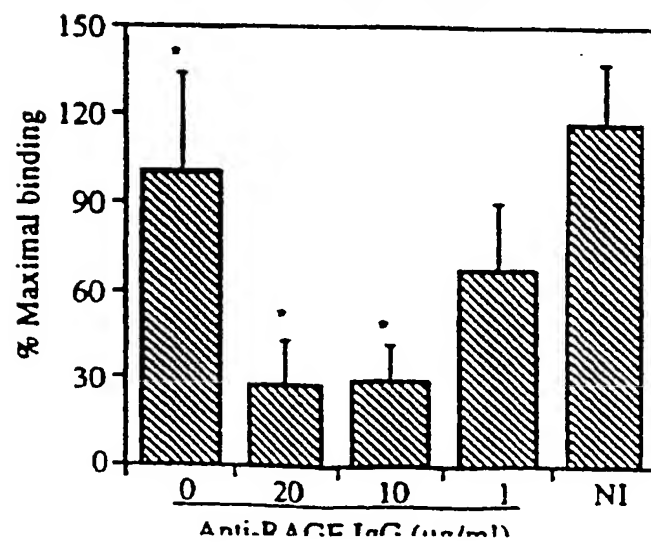


FIG. 5C



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FIG. 6A

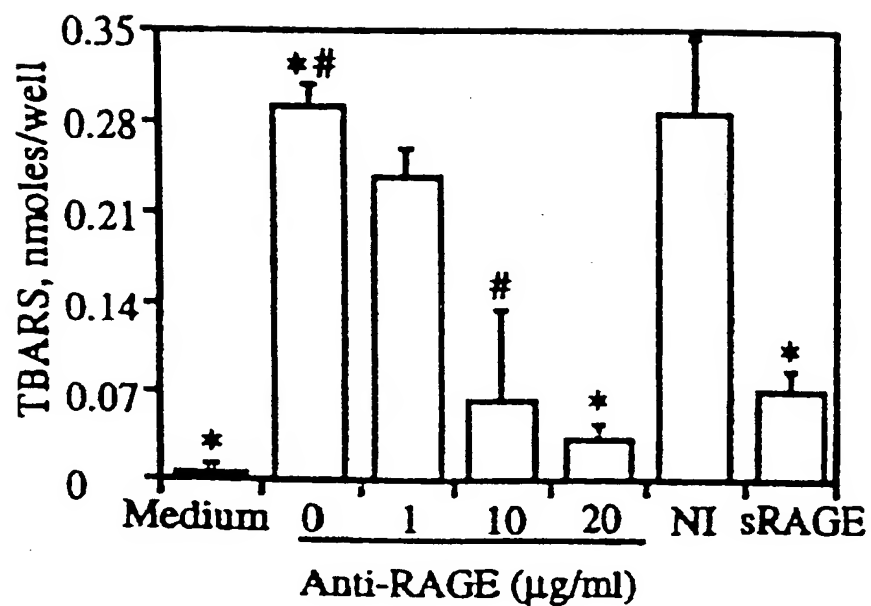
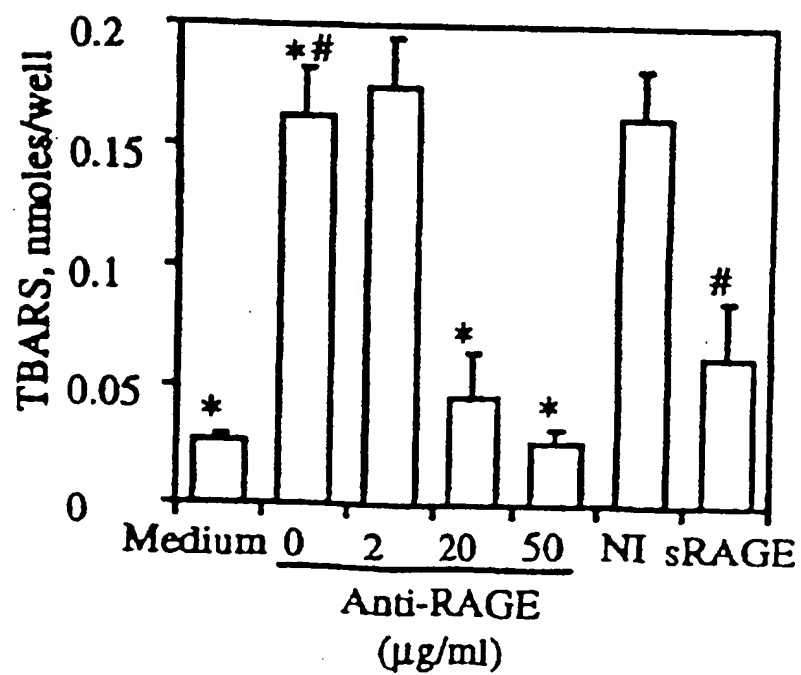


FIG. 6B



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FIG. 6C

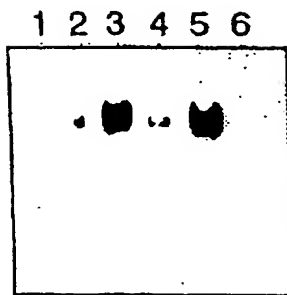


FIG. 6D



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FIG. 7A

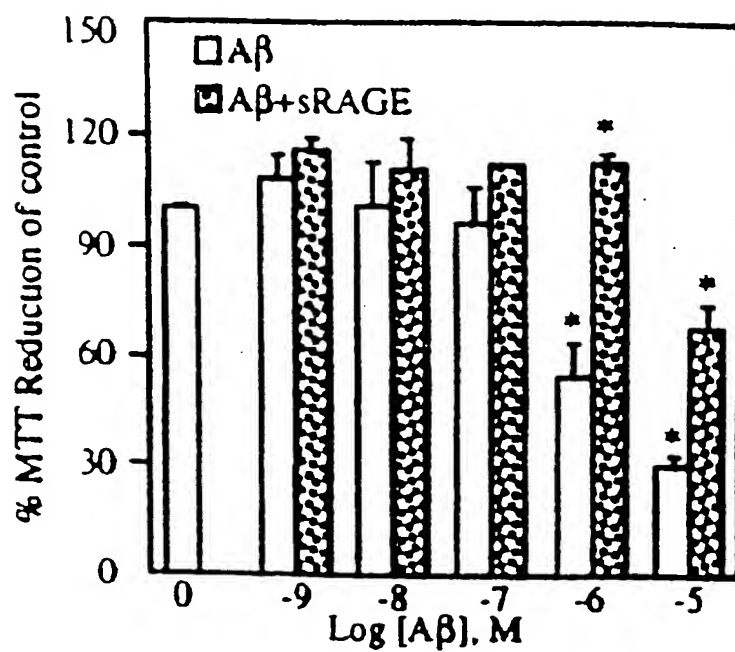
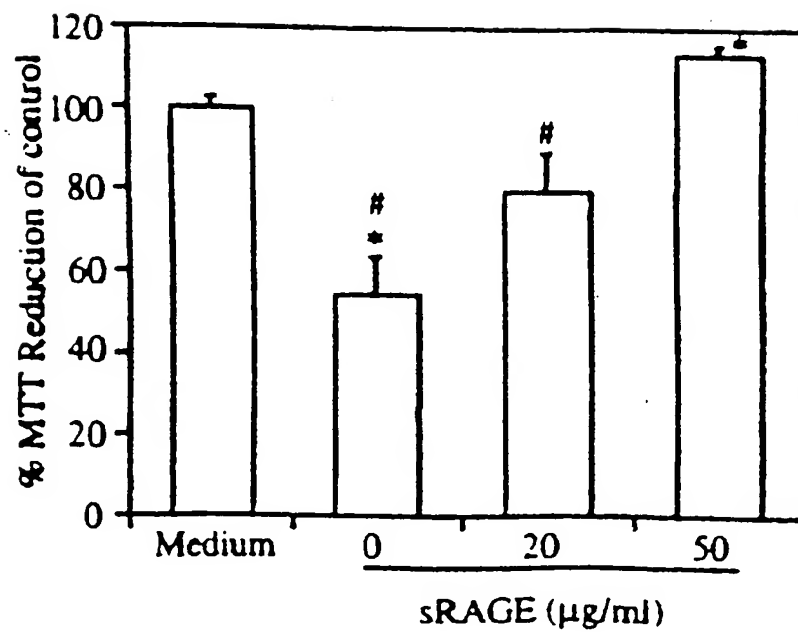


FIG. 7B



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FIG. 7C

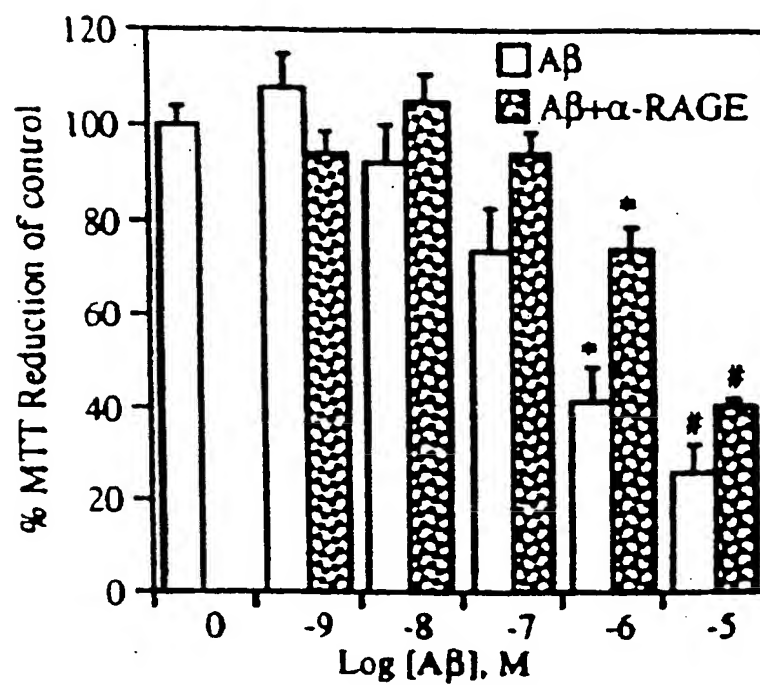
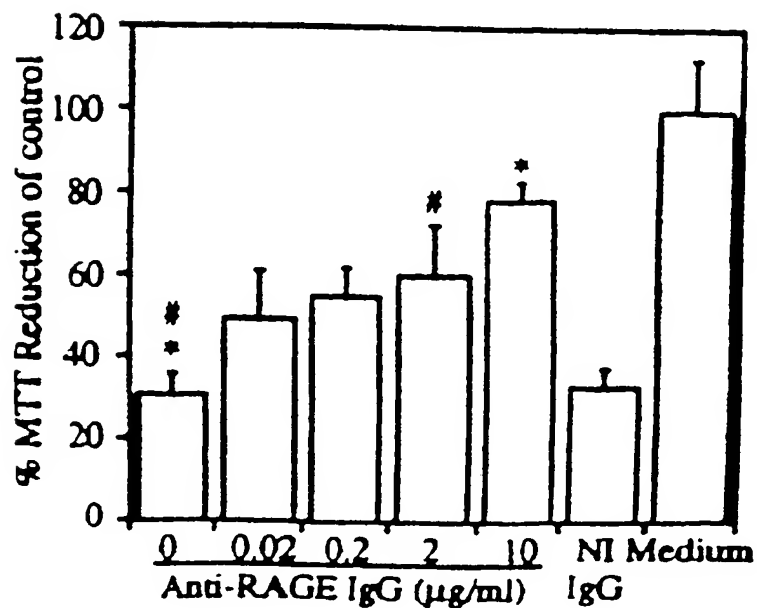


FIG. 7D



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FIG. 7E

FIG. 7F

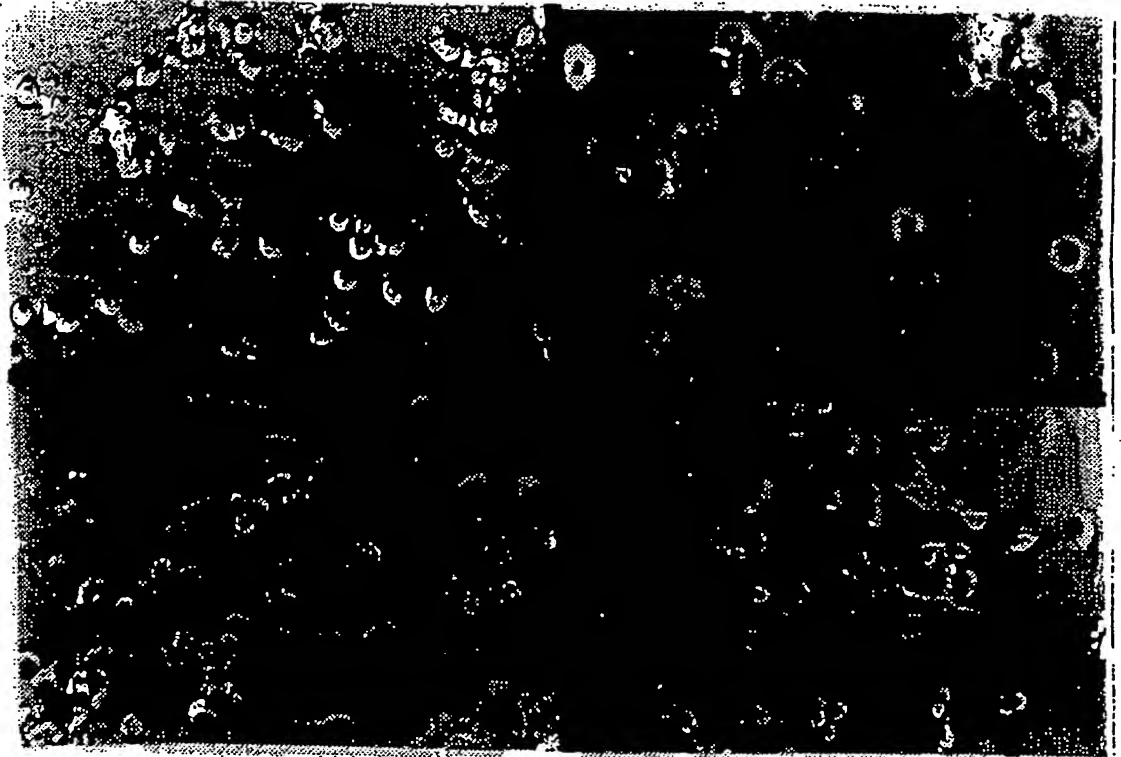


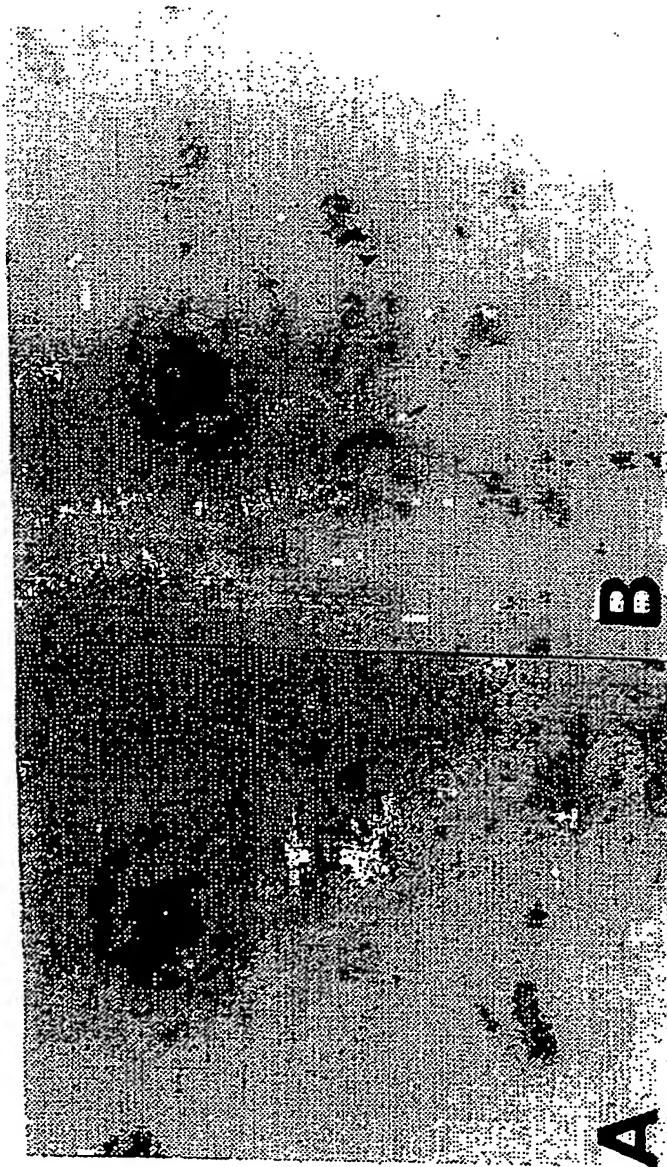
FIG. 7G

FIG. 7H

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FIG. 8B

FIG. 8A



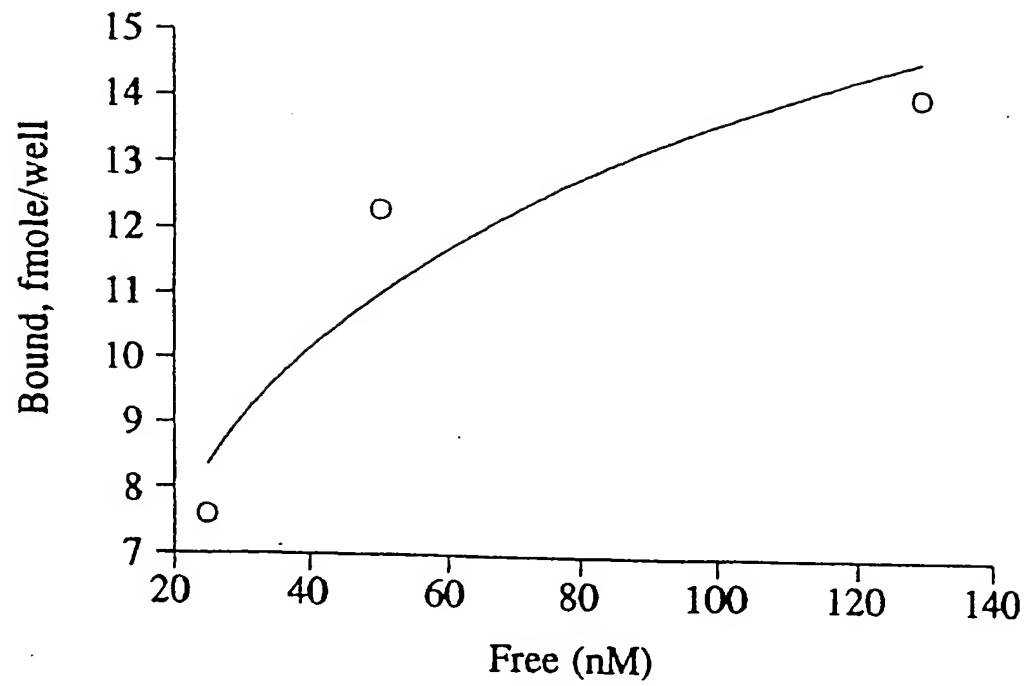
RAGE

CD68



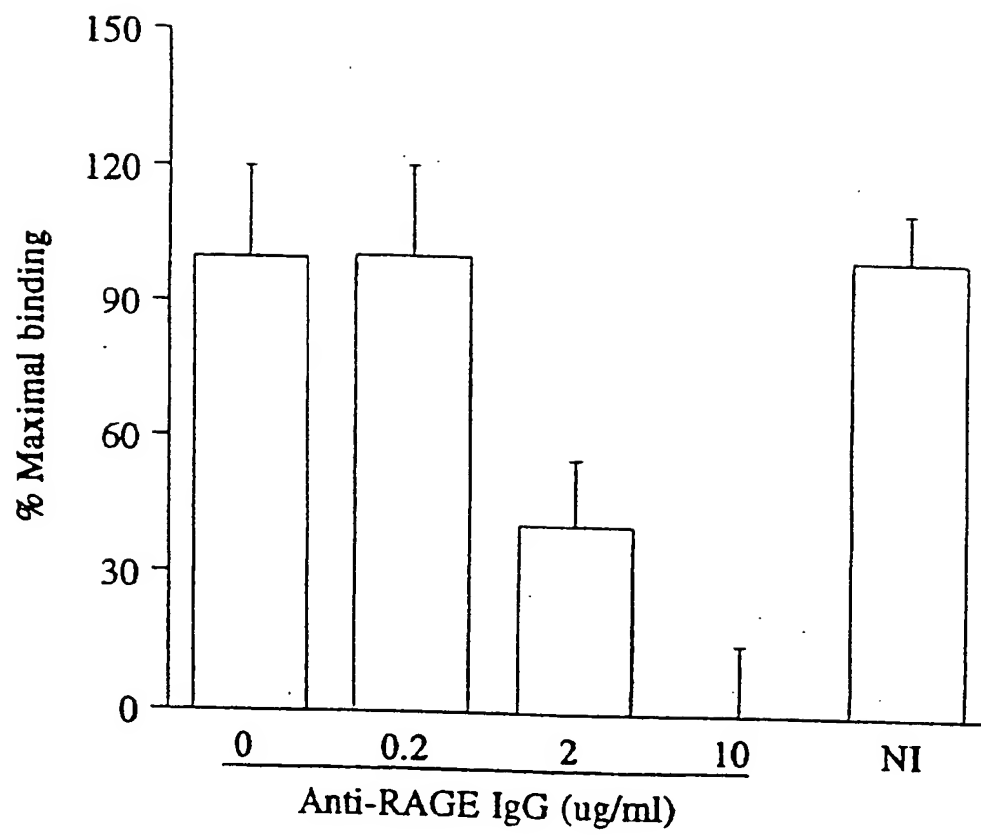
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FIG. 9A



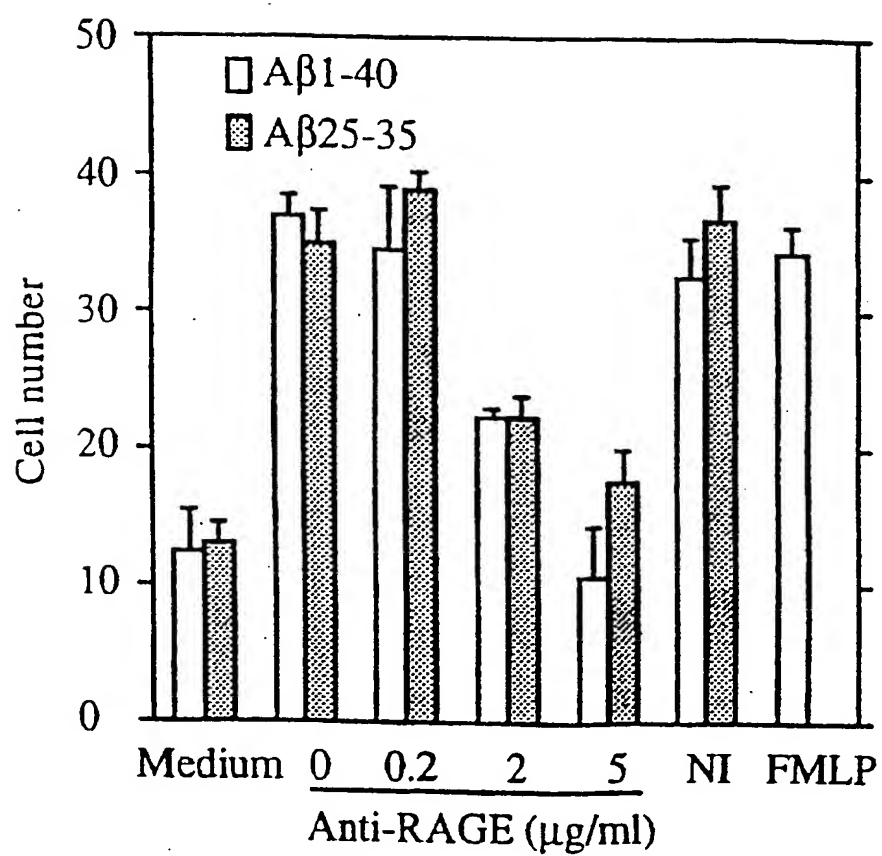
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FIG. 9B



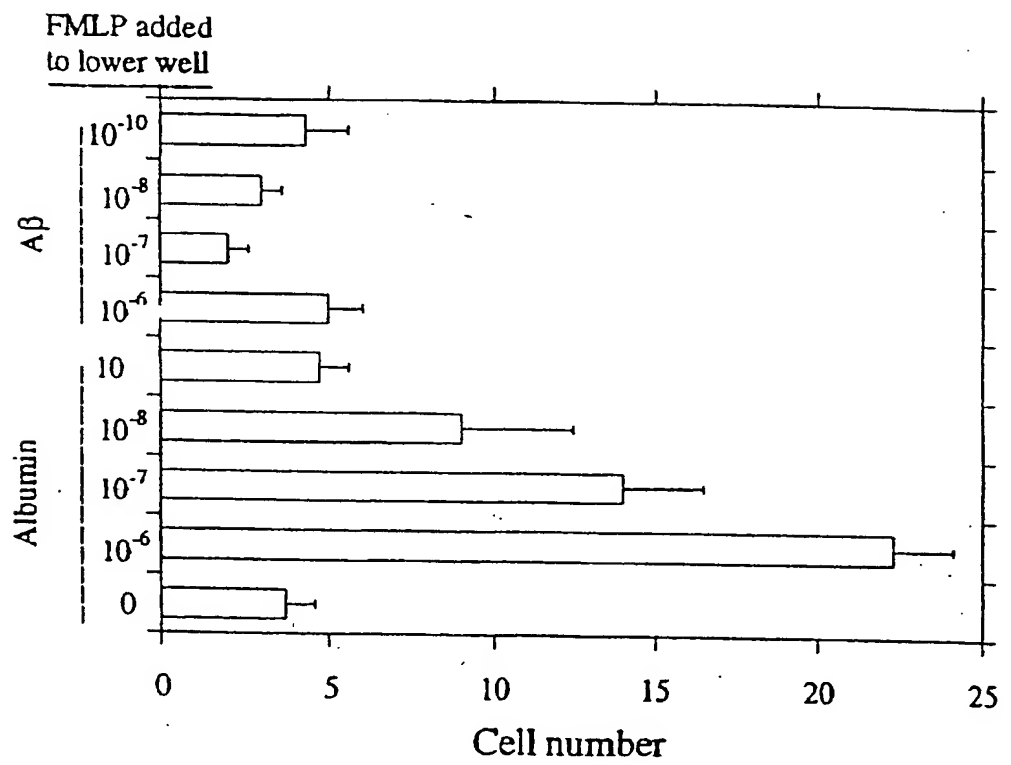
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FIG. 10A



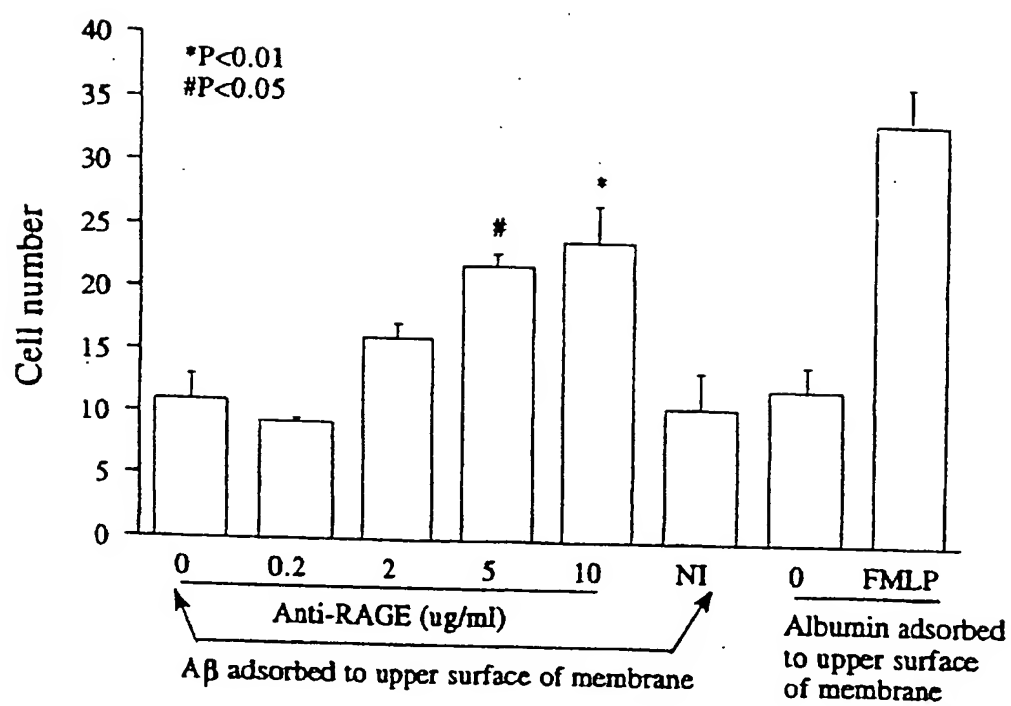
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FIG. 10B



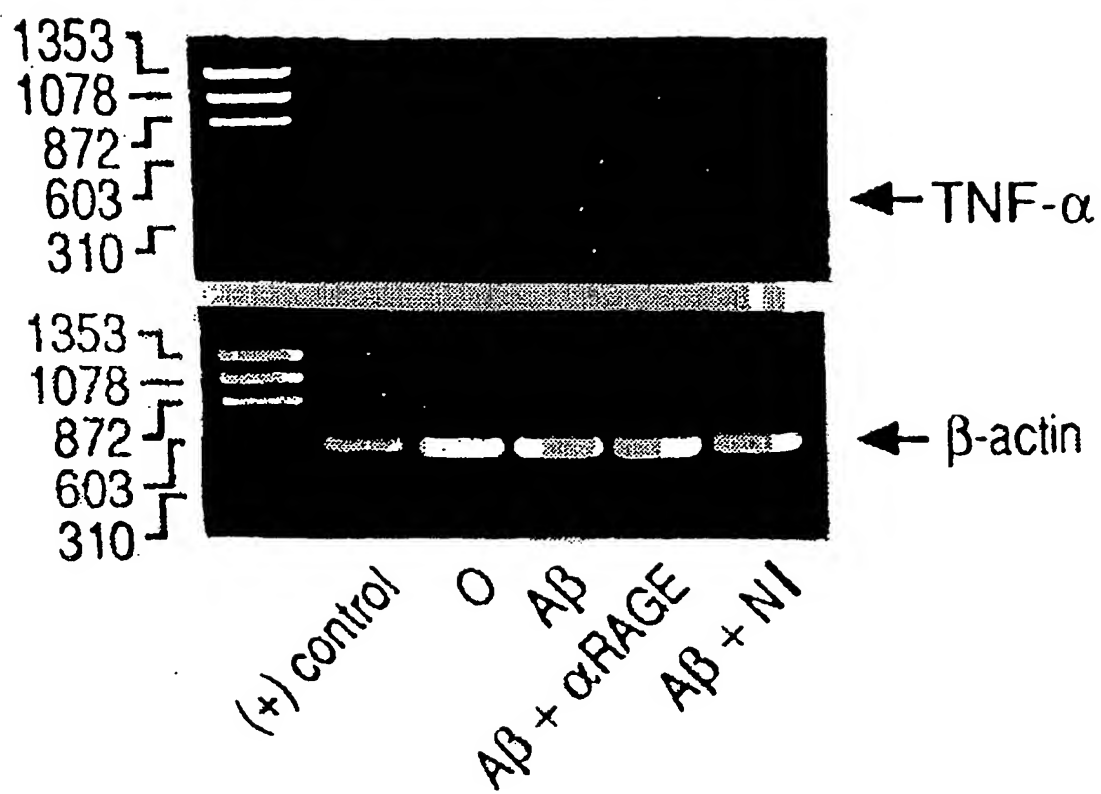
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FIG. 10C



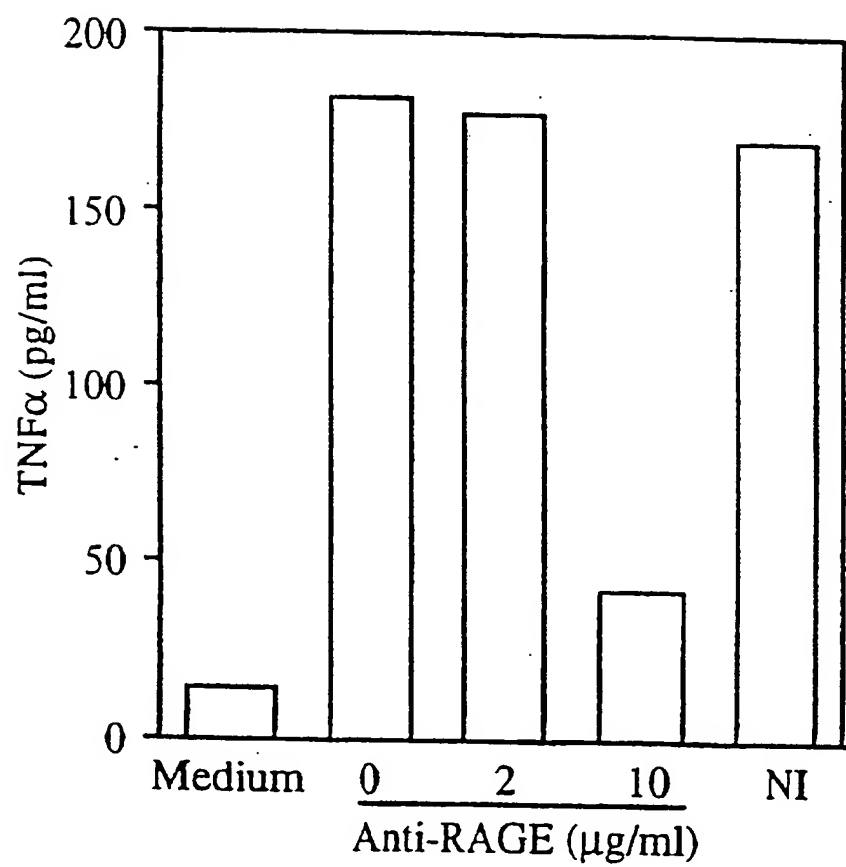
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FIG. 11A



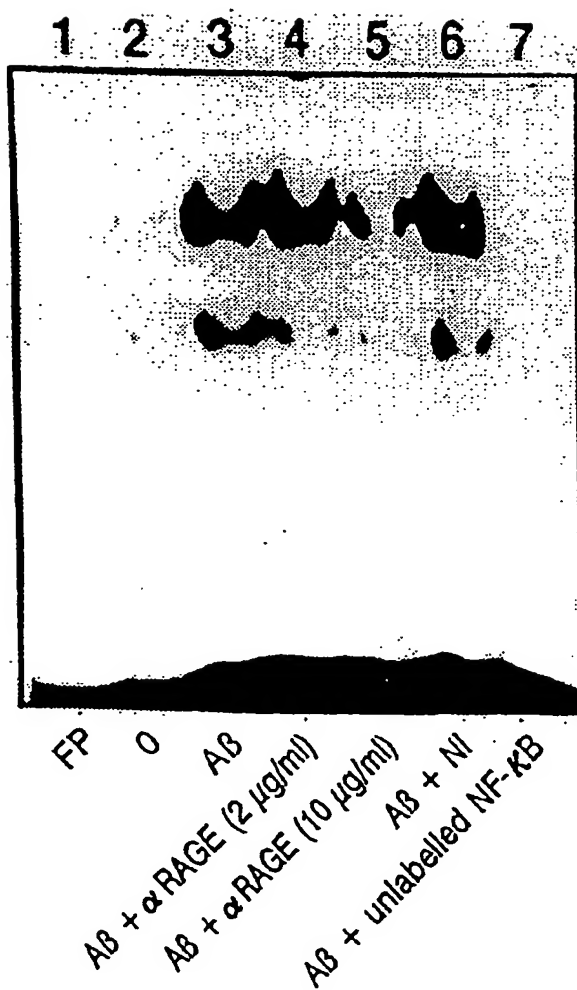
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FIG. 11B



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FIG. 11C





## INTERNATIONAL SEARCH REPORT

International application No.

PCT/US97/00857

## A. CLASSIFICATION OF SUBJECT MATTER

IPC(6) : A61K 39/395; A61K 38/00; C07K16/00

US CL : 424/130.1; 514/2, 44; 530/300, 387.1

According to International Patent Classification (IPC) or to both national classification and IPC

## B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)

U.S. : 424/130.1; 514/2, 44; 530/300, 387.1

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

Electronic data base consulted during the international search (name of data base and, where practicable, search terms used)

APS, DIALOG, MPSRCH

search terms: advanced glycation end product, receptor, amyloid-beta peptide, inhibit, binding, antibody.

## C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X -- Y	WO 95/06477 A1, (GLIATECH, INC.), 09 March 1995. See entire document, especially claim 49, page 64.	70-71 ----- 1-15, 24, 49-68
X -- Y	WO 93/04194 A1, (REGENTS OF THE UNIVERSITY OF MINNESOTA), 04 March 1993. See entire document.	70-71 ----- 1-15, 24, 49-68
X -- Y	WO 94/17197 A1, (TAKEDA CHEMICAL INDUSTRIES, LTD), 04 August 1994. See entire document.	70-71 ----- 1-15, 24, 49-68

☒ Further documents are listed in the continuation of Box C. ☐ See patent family annex.

* Special categories of cited documents:	* T	later document published after the international filing date or priority date and not in conflict with the application but cited to understand the principle or theory underlying the invention
* A document defining the general state of the art which is not considered to be of particular relevance	* X	document of particular relevance; the claimed invention cannot be considered novel or cannot be considered to involve an inventive step when the document is taken alone
* E earlier document published on or after the international filing date	* Y	document of particular relevance; the claimed invention cannot be considered to involve an inventive step when the document is combined with one or more other such documents, such combination being obvious to a person skilled in the art
* L document which may throw doubts on priority claim(s) or which is cited to establish the publication date of another citation or other special reason (as specified)	* &	document member of the same patent family
* O document referring to an oral disclosure, use, exhibition or other means		
* P document published prior to the international filing date but later than the priority date claimed		

Date of the actual completion of the international search

23 MARCH 1997

Date of mailing of the international search report

19 MAY 1997

Name and mailing address of the ISA/US  
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## INTERNATIONAL SEARCH REPORT

International application No.  
PCT/US97/00857

## C (Continuation). DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
Y	NEEPER et al. Cloning and expression of a cell surface receptor for advanced glycosylation end products of proteins. The Journal of Biological Chemistry. 25 July 1992, Vol. 21, pages 14998-15004. See entire document.	1-15, 24, 49-68, 70-71

# INTERNATIONAL SEARCH REPORT

International application No.  
PCT/US97/00857

## Box I Observations where certain claims were found unsearchable (Continuation of item 1 of first sheet)

This international report has not been established in respect of certain claims under Article 17(2)(a) for the following reasons:

1. ☐ Claims Nos.:  
because they relate to subject matter not required to be searched by this Authority, namely:
  
2. ☐ Claims Nos.:  
because they relate to parts of the international application that do not comply with the prescribed requirements to such an extent that no meaningful international search can be carried out, specifically:
  
3. ☐ Claims Nos.:  
because they are dependent claims and are not drafted in accordance with the second and third sentences of Rule 6.4(a).

## Box II Observations where unity of invention is lacking (Continuation of item 2 of first sheet)

This International Searching Authority found multiple inventions in this international application, as follows:

See attached pages.

1. ☐ As all required additional search fees were timely paid by the applicant, this international search report covers all searchable claims.
2. ☐ As all searchable claims could be searched without effort justifying an additional fee, this Authority did not invite payment of any additional fee.
3. ☐ As only some of the required additional search fees were timely paid by the applicant, this international search report covers only those claims for which fees were paid, specifically claims Nos.:
  
4. ☒ No required additional search fees were timely paid by the applicant. Consequently, this international search report is restricted to the invention first mentioned in the claims; it is covered by claims Nos.:  
1-15, 24, 49-68, 70-71

Remark on Protest

- ☐ The additional search fees were accompanied by the applicant's protest.  
☐ No protest accompanied the payment of additional search fees.

## INTERNATIONAL SEARCH REPORT

International application No.  
PCT/US97/00857

### BOX II Observations where unity of invention is lacking

This application contains the following inventions or groups of inventions which are not so linked as to form a single inventive concept under PCT Rule 13.1. In order for all inventions to be searched, the appropriate additional search fees must be paid.

Group I, claims(s) 1-15, 24, 49-68, and 70-71 drawn to 1) a method for inhibiting interaction of an amyloid-beta peptide with a receptor for advanced glycation end product, comprising contacting the cell with an agent capable of inhibiting said interaction, and 2) a composition comprising said agent.

Group II, claim(s) 16, drawn to a method for inhibiting degeneration of a neuronal cell.

Group III, claim(s) 17-20, drawn to a method for inhibiting formation of an amyloid-beta peptide fibril, or aggregation of amyloid-beta peptide on a cell.

Group IV, claim(s) 21-23, drawn to a method for inhibiting infiltration of a microglial cell into senile plaques, or inhibiting activation of a microglial cell.

Group V, claim(s) 25-48, drawn to a method for treating diseases, comprising administering to the subject an agent capable of inhibiting the interaction of the amyloid-beta peptide with the receptor for advanced glycation end product.

Group VI, claim(s) 69, drawn to a method for inhibiting activation of an NF-kB gene in a cell.

The inventions listed as Groups I-VI do not relate to a single invention concept under PCT Rule 13.1 because, under PCT Rule 13.2, they lack the same or corresponding special technical features for the following reasons:

In the instant case, the shared inventive concept joining these methods would appear to be inhibiting interaction of an amyloid-beta peptide with a receptor for advanced glycation end product by an agent. In order for the invention of Group I to have unity of invention, it is necessary that the single inventive concept be a contribution over the prior art. However, the teachings of WO 95/06477, WO 93/04194, and WO 94/17197 suggest the use of peptides or antibodies for the inhibition of interaction of an amyloid-beta peptide with a receptor for advanced glycation end product, and thus, defeat unity. In conclusion, the invention of claims 1-71 do not fulfill the requirement for unity of invention, and each method of use forms basis of an individual group.